ERDC Letter Report

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Evaluation of the San Jacinto Waste Pits Feasibility Study Remediation Alternatives

March 2015

Earl Hayter, Paul Schroeder, Susan Bailey, Natalie Rogers, Joe Kreitinger, Carlos Ruiz, and Mike Channell

Lower San Jacinto River

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Letter Report

Prepared for U.S. EPA, Region 6
Dallas, TX 75202

Abstract

The U.S. Army Engineer Research and Development Center (ERDC) is providing technical support to the US Environmental Protection Agency (EPA), the goal of which is to prepare an independent assessment of the Potentially Responsible Parties' (PRP) remedial alternative designs for the San Jacinto River Waste Pits Superfund Site, Texas. Specific objectives of this study are the following:

1) Perform an assessment of the design and evaluation of the remediation alternatives presented in the Feasibility Study.
2) Identify other remedial action alternatives or technologies that may be appropriate for the Site.
3) Evaluate the numerical models used by the PRP's modeling contractor for the Site.
4) Assess the hydraulic conditions in and around the San Jacinto River, and utilize surface water hydrologic, hydrodynamic, and sediment transport models appropriate for the Site in performing the assessment.

This is the second of three reports that will be submitted to the EPA, and reports on nine of the 20 tasks that were identified by EPA for the ERDC to perform to accomplish the stated goal and objectives.

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Preface

This study was performed at the request of the U.S. Environmental Protection Agency (EPA) – Region 6 by the Environmental Laboratory (ERDC-EL) of the US Army Corps Engineer Research and Development Center (ERDC), Vicksburg, MS.

At the time of publication, the Deputy Director of ERDC-EL was Dr. Jack Davis and the Director of ERDC-EL was Dr. Elizabeth C. Fleming. Commander of ERDC was COL Jeffrey R. Eckstein. The Director was Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
miles (U.S. nautical)	1,.852	kilometers
miles (U.S. statute)	1.609347	kilometers
acres	4,046.873	Square meters
cubic yards	0.7645549	cubic meters
knots	0.5144444	Meters per second

1 Project Background, Objectives and Tasks

Background

The San Jacinto River Waste Pits Superfund Site (Site) consists of several waste ponds, or impoundments, approximately 14 acres in size, built in the mid-1960s for the disposal of paper mill wastes as well as the surrounding areas containing sediments and soils potentially contaminated by the waste materials that had been disposed of in these impoundments. The impoundments are located immediately north and south of the I-10 Bridge and on the western bank of the San Jacinto River in Harris County, Texas (see Figure 1-1).

Large scale groundwater extraction has resulted in regional subsidence of land in proximity to the Site that has caused the exposure of the contents of the northern impoundments to surface waters. A time-critical removal action was completed in 2011 to stabilize the pulp waste material in the northern impoundments and the sediments within the impoundments to prevent further release of dioxins, furans, and other chemicals of concern into the environment. The removal consisted of placement of a temporary armor rock cap over a geotextile bedding layer and an impermeable geomembrane in some areas. The total area of the temporary armor cap is 15.7 acres. The cap was designed to withstand a 100-year storm event.

The southern impoundments are located south of I-10 and west of Market Street, where various marine and shipping companies have operations (see Figure 1-1). The area around the former southern impoundments is an upland area that is not currently in contact with surface water.

The members of the ERDC-EL Project Delivery Team (PDT) have provided technical assistance to the Site's Remedial Project Manager (RPM) for the past three years that consisted of 1) an evaluation of modeling performed by the modeling contractor for the Potentially Responsible Parties (PRP), 2) an evaluation of the design of the temporary armor cap, and 3) review of the Feasibility Study submitted by the RP.

Figure 1-1 San Jacinto River Waste Pits Superfund Site

Goal and Objectives

The goal of this study is to provide technical support to US Environmental Protection Agency (EPA), including preparing an independent assessment of the PRP's designs and submittals regarding the San Jacinto River Waste Pits Superfund Site. Specific objectives of this study are the following:

1) Perform an assessment of the design and evaluation of the remediation alternatives presented in the Feasibility Study.
2) Identify other remedial action alternatives or technologies that may be appropriate for the Site.
3) Evaluate the numerical models used by the PRP's modeling contractor for the Site.
4) Assess the hydraulic conditions in and around the San Jacinto River, and utilize surface water hydrologic, hydrodynamic, and sediment transport models appropriate for the Site in performing the assessment.

Study Tasks

The following specific tasks were identified by EPA for the PDT to perform to accomplish the stated goal and objectives.

Task 1: Site Visit and Planning Meeting. This task was performed in mid-November.

Task 2: Perform an assessment of the San Jacinto River flow/hydraulic conditions and river bed scour in and around the Site for severe storms, hurricanes, storm surge, etc., using surface water hydrology model(s) appropriate for the Site. In the assessment include an evaluation of potential river bed scour/erosion in light of the historical scour reports for the Banana Bend area and for the San Jacinto River south of the I-10 Bridge.

Task 3: Perform an evaluation of the models and grid cell sizes used by the PRPs for the Site, and include a discussion of any uncertainties in the model results. The evaluation should include a review of the model assumptions regarding bed shear stress, water velocities, and scour.

Task 4: Provide an uncertainty analysis of the model assumptions (flow rates, boundary representation, sediment transport, sedimentation rates, initial bed properties, etc.). Uncertainties should be clearly identified and assessed including sediment loads at the upstream Lake Houston Dam.

Task 5: Perform a technical review of the design and construction of the entire existing cap as it is currently configured. Identify any recommended enhancements to the cap.

Task 6: Assess the ability of the existing cap to prevent migration of dioxin, including diffusion and/or colloidal transport, through the cap with and without the geomembrane/geotextile present.

Task 7: Assess the long-term reliability (500 years) of the cap under the potential conditions within the San Jacinto River, including severe storms, hurricanes, storm surge, subsidence, etc. Include in the assessment an evaluation of the potential for cap failure that may result from waves, prop wash, toe scour and cap undermining, rock particle erosion, substrate material erosion, stream instability, and other potential failure mechanisms. Reliability will be based on the ability of the cap to prevent any release of contaminated material from the Site. Also discuss any uncertainty regarding the long-term reliability and effectiveness of the existing cap.

Task 8: As part of the cap reliability evaluation, assess the potential impacts to the cap of any barge strikes/accidents from the nearby barge traffic.

Task 9: Identify what institutional/engineering controls (*e.g.*, deed restrictions, notices, buoys, signs, fencing, patrols, and enforcement activities) should be incorporated into the remedial alternatives for the TCRA area and surrounding waters and lands.

Task 10: Identify and document cases, if any, of armoring breaches or confined disposal facility breaches that may have relevance to the San Jacinto site evaluation.

Task 11: Assess the potential amount or range of sediment resuspension and residuals under the various remedial alternatives including capping, solidification, and removal.

Task 12: Identify and evaluate techniques, approaches, Best Management Practices (BMPs), temporary barriers, operational controls, and/or engineering controls (*i.e.*, silt curtains, sheet piles, berms, earth cofferdams, etc.) to minimize the amount of sediment resuspension and sediment residuals concentrations during and after dredging/removal. Prepare a new full removal alternative that incorporates the relevant techniques identified as appropriate.

Task 13: Assess the validity of statements made in the Feasibility Study that the remedial alternative with removal, solidification, and placing wastes again beneath the TCRA cap has great uncertainty as to implementation and that such management of the waste will result in significant releases.

Task 14: Provide a model evaluation of the full removal Alternative 6N identified in the Feasibility Study as well any new alternative(s) developed under Task 12 (Identify and evaluate techniques …) above. Include modeling of sediment resuspension and residuals.

Task 15: Evaluate floodplain management and impact considerations of construction, considering Alternatives 3N, 5aN, 6N, and any new alternative(s) developed under Task 12, in the floodplain and floodwaters pathway and how that would impact flood control, water flow issues and obstructions in navigable waters. This includes impact on changes to potential flooding and any offsets that are needed due to displacement of water caused by construction in the floodway (height or overall footprint) including effects at the current temporary TCRA cap and any potential future remedial measures.

Task 16: Project the long-term (500 years) effects of the capping alternative (3N) compared to the full removal alternative (6N) on water quality.

Task 17: Assess the potential impacts to fish, shellfish, and crabs from sediment resuspension as a result of dredging in the near term and for the long term.

Task 18: Assess the potential for release of material from the waste pits caused by a storm occurring during a removal/dredging operation; identify and evaluate measures for mitigating/reducing any such releases.

Task 19: Estimate the rate of natural attenuation in sediment concentrations/residuals and recommend a monitoring program to evaluate the progress. Discuss the uncertainty regarding the rate of natural attenuation.

Task 20: Assess the appropriateness of the preliminary sediment remediation action level of 220 *ng/kg* in consideration of the appropriate exposure scenario (recreational vs. subsistence fishing), and in consideration of an appropriate Relative Bio-Availability (RBA) factor; and recommend an alternative sediment action level as appropriate.

Study Plan

This first report includes a description of the work performed by the PDT for Tasks 2 - 6. The second report, to be submitted to EPA by 27 February, will describe the work to be performed for Tasks 7 – 14 and 20. The third report, to be submitted to EPA by 10 April, will describe the work to be performed for Tasks 15 – 19. Each of these tasks will be in its own subsection of the next Section entitled Project Tasks. The second and third reports will be added to this Letter Report. Each of these three reports will be reviewed by the Site RPM and his team. The final version of the report, which will include the report for all the tasks, will include the revisions directed by the Site RPM.

2 Project Tasks

The report on Tasks 2 – 14 and 20 are included in this section.

Task 2

Statement

Perform an assessment of the San Jacinto River (SJR) flow/hydraulic conditions and river bed scour in and around the Site for severe storms, hurricanes, storm surge, etc., using surface water hydrology model(s) appropriate for the Site. In the assessment include an evaluation of potential river bed scour/erosion in light of the historical scour reports for the Banana Bend area and for the SJR south of the I-10 Bridge.

Findings

This task was performed by first reading all identified resources (*e.g.*, reports, journal papers, local sources including newspapers) that describe the hydrologic and hydraulic conditions in the Lower SJR. This information assisted in performing the requested assessment of the SJR hydrodynamic regime. Taking into account the historical scour reports for the Banana Bend area and for the SJR south of the I-10 Bridge, the evaluation of the potential river bed scour/erosion was performed by applying ERDC's LTFATE modeling system to simulate the flood conditions during the October 1994 flood.

Hydrology and Hydrodynamics of the San Jacinto River

The lower SJR is classified as a coastal plain estuary. Dyer (1997) gives the following definition of an estuary: "An estuary is a semi-enclosed coastal body of water which has a free connection to the open sea, extending into the river as far as the limit of tidal influence, and within which sea water is measurably diluted with fresh water derived from land drainage." Land drainage is from the SJR watershed which is a 4,500 square mile area in Harris County, TX. Bedient (2013) reports that this watershed drains an average of approximately two million acre-feet (2.47 km^3) of runoff per year. The SJR connects to Galveston bay which has open connections to the Gulf of Mexico.

The SJR Waste Pits are located in a FEMA designated floodway zone, which is essentially the 100-year floodplain for the SJR. The base flood elevation, which is the water surface elevation resulting from a 100-year flood, for the waste pits has been determined by FEMA to be 19 feet (5.8 m). The low lying Waste Pits are also subject to flooding from storm surges generated by both tropical storms (*i.e.*, hurricanes) and extra-tropical storms. Storm surges generated in the Gulf of Mexico propagate into Galveston Bay and into the Lower SJR. Storm surge modeling conducted by NOAA predicted that category 3 and 5 hurricanes that hit Galveston Bay during high tide would produce surge levels of 23 ft (7.0 m) and 33 ft (10.1 m), respectively, at the Site. In addition, eustatic sea level rise and subsidence also contributes to the vulnerability of the Site. The combined effect of sea level rise and subsidence is reflected in the 1.97 ft (0.6 m) increase in relative sea level rise recorded over the past 100 years in Galveston Bay (Brody *et al*. 2014).

The dynamic nature of the flow regime in the SJR estuary is exemplified by the flood that occurred from October 15-19, 1994. The flood was caused by rainfall that ranged from 8 to more than 28 inches during this five day period and caused severe flooding in portions of 38 counties in southeast Texas (USGS 1995). The 100-year flood was equaled at three of the 43 streamflow gauging stations in the 29 counties that were declared disaster areas after the flow, and it was exceeded at 16 stations. The exceedance of the 100-year flood at the 16 stations ranged from a factor of 1.1 to 2.9 times the 100-year flood. In addition, at 25 of the 43 stations, the peak stages during the flood exceeded the historical maximums (USGS 1995). This flood had a 360,000 ft^3/s (cfs) (10,194 m^3/s (cms)) peak streamflow, 27.0 ft (8.2 m) peak stage, and current velocities greater than 15 ft/s (4.6 m/s) at a gage station on the SJR near Sheldon when up to eight feet of scour was observed in the reach of the SJR south of the I-10 Bridge. The photo on the front cover of this report shows the inundated Site during this flood.

As another example, Hurricane Ike, which was a category 2 hurricane, hit Galveston Bay on September 15, 2008. While this hurricane was less than a 100-year storm, it produced a large storm surge that completely inundated the Site and generated a peak flow rate of 63,100 cfs (1,787 cms) at the Lake Houston Dam. Tropical Storm Allison hit the Galveston Bay area on June 10, 2001, and generated a peak flow rate at the Lake Houston Dam of 80,500 cfs (2,280 cms).

Evaluation of Potential River Bed Scour

As stated previously, the evaluation of the potential river bed scour/erosion was performed by applying ERDC's LTFATE modeling system to simulate the flood conditions during the October 1994 flood. LTFATE is a multi-dimensional modeling system maintained by ERDC. The hydrodynamic module in LTFATE is the Environmental Fluid Dynamics Code (EFDC) surface water modeling system (Hamrick 2007a; 2007b; and 2007c). EFDC is a public domain, three-dimensional finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. The sediment transport module in LTFATE is the SEDZLJ sediment bed model (Jones and Lick 2001; James *et al*. 2010). A detailed description of LTFATE is given in Appendices A – C. Appendix A contains a general description of the modeling system, Appendix B contains a detailed description of EFDC, and Appendix C contains a description of SEDZLJ. The setup of LTFATE for this estuarine system is described in Task 3.

The hydrodynamic module in LTFATE was used to simulate the time period September 1 – 30, 2008 using the hydrodynamic input files generated by AQ. This simulation produced a hydrodynamic hot start file that was used to simulate the October 1 – 31, 2008 time period during which sediment transport was also simulated. The simulation showed that the Site was completely inundated during this flood (as seen on the photo on the report cover), and that a maximum of 5.8 ft (1.8 m) of scour was predicted to occur in reach of the SJR south of the I-10 Bridge. This simulation was run using only a partially calibrated and validated LTFATE model. Once calibration and validation are complete, the simulation of the September – October time period will be re-run. Updated results (including figures showing the variation in scour and sedimentation depths in proximity to the Site and I-10) will be included in the final report.

Task 3

Statement

Perform an evaluation of the models and grid cell sizes used by the PRPs for the Site, and include a discussion of any uncertainties in the model results. The evaluation should include a review of the model assumptions regarding bed shear stress, water velocities, and scour.

Findings

This task was performed in two steps. The first step consisted of evaluating AQ's models, which included evaluating the impact of the assumptions included in AQ's model framework for their hydrodynamic and sediment transport models, and the second step consisted of setting up ERDC's LTFATE modeling system whose framework does not contain as many assumptions. The second step was performed to quantify the differences between the two modeling systems during select high flow events. As stated previously, LTFATE is described in Appendices A – C. The work performed on this task is described below.

1. Evaluation of AQ's models

The model evaluation process began with the transfer of AQ's model files, including source code, scenario inputs and outputs, and calibration/validation data, and modeling reports to the EPA and the PDT. The review and evaluation of the models included evaluation of model inputs, verification of model code, and benchmarking of model results. More specifically, the methodology used in performing this evaluation was the following:

1. Modeling System Application: Review the application of the AQ models to the SJR estuarine system; specifically evaluate the procedures used to setup, calibrate and validate the models as well as the assumptions included in the AQ model framework.
2. Model Evaluation: a) Evaluate model input files (including model-data comparisons) used for calibration and validation run of both models. b) Verify that the model codes are correctly representing the simulated hydrodynamic and sediment transport processes. c) Benchmark the models by running the models using

the calibration/validation input files and comparing results with those given in AQ's Modeling Report.

Modeling System Application

The applications of the hydrodynamic and sediment transport model components of the AQ modeling system to the SJR are discussed in this section.

The application of AQ's Environmental Fluid Dynamics Code (EFDC) to the SJR model domain was thoroughly reviewed, taking into consideration the constraints of their modeling framework. Specific concerns (the first sentence for each concern is bolded) related to the application of their hydrodynamic and sediment transport models are discussed below.

The location of the downstream boundary of the model domain. As noted by several reviewers, the chosen location required the use of interpolated tidal boundary conditions. EPA's comments to AQ on this subject included the following:

> "The hydraulic regime at the confluence of the Houston Ship Channel at the SJR (Battleship Texas gauge station) is fundamentally different than that which occurs at the mouth of the SJR at Galveston Bay (Morgan's Point gauge station). While approximately symmetrical tidal currents can be expected at both the Battleship Texas and Morgan's Point gauge stations during non-event periods, the symmetry should not exist during periods of flooding. A decoupling of water surface elevations between stations is expected during flood events due to a local heightening of water surface elevation from increased freshwater flow at the mouth of the Houston Ship Channel compared to that of the more tidal-influenced, more open marine environ of Galveston Bay (*e.g.*, Thomann, 1987). Consequently, the water surface elevation response at the downgradient model domain boundary (Battleship Texas) would be significantly different than the water surface elevation response downstream at Galveston Bay (Morgan's Point) during a flood or surge event. As such, the use of data from Morgan's Point may be inappropriate for use in calibrating the subject model."

Regarding this issue, Anchor QEA (2012) states that "sensitivity analysis was conducted to evaluate the effect of using WSE data collected at Morgan's Point on hydrodynamic and sediment transport model predictions (see Section 4.4).” In Section 4.4 it states the following:

> “Analysis of the effects of data source for specifying WSE at the downstream boundary of the model was accomplished by simulating 2002 using data collected at the Lynchburg gauge station. This year was chosen because it was the only year during which Battleship Texas State Park or Lynchburg WSE data are available and one or more high-flow events (*i.e.*, 2-year flood or greater) occurred. Cumulative frequency distributions of bed elevation changes within the USEPA Preliminary Site Perimeter for the base case and sensitivity simulations are compared on Figure 4-59. Differences in bed elevation change between the two simulations are between -2 and +2 cm over of the bed area in the USEPA Preliminary Site Perimeter (Figure 4-60, bottom panel). A one-to-one comparison of bed elevation changes for each grid cell within the USEPA Preliminary Site Perimeter is presented on Figure 4-60. Overall, the data source for specifying WSE at the downstream boundary of the hydrodynamic model has minimal effect on sediment transport within the USEPA Preliminary Site Perimeter.”

The PDT disagrees with the approach used in this analysis of the effects of data source for the WSE. With the differences in the hydrodynamic regimes during floods as described by several of EPA’s reviewers, the PDT disagrees with AQ’s justification that is based on differences in simulated bed elevation changes within the Site. Just because the differences in bed elevation changes over a one year simulation using the two different WSE data sources were within ± 2 cm does not indicate that the circulation pattern in the estuary was correctly simulated. If it was not, then the fate of eroded contaminated sediment would be different. As such, the PDT still believes that the more appropriate boundary location would have been in the vicinity of Morgan’s Point due to the NOAA tidal station (Number 8770613) at that location. This is where the downstream boundary for the LTFATE model domain was located.

Decoupled hydrodynamic and sediment transport models. The main limitation of AQ’s model framework is the use of decoupled hydrodynamic and sediment transport models. This limits its applicability to flow conditions when large morphologic changes (relative to the local flow depth) due to net erosion and net deposition do not occur. Thus, it is not capable of simulating morphologic changes during large flood events, such as the previously described October 1994 flood. Anchor QEA (2012) states that “model reliability is not significantly affected by not incorporating direct feedback between the hydrodynamic and sediment transport models into the modeling framework, with approximately 8% of the bed area experiencing relative increases or decreases in potential water depth of greater than 20%.” However, since these results, *i.e.*, “8% of the bed area …”, were obtained using a modeling framework that did not account for changes in bed elevation due to erosion and deposition, which means that those results are in question, they cannot be used to justify not including direct feedback into the modeling framework.

Floodplain areas. Anchor QEA (2012) states that “Floodplain areas (*i.e.*, areas that only get inundated during high flow events) were incorporated into the rectangular numerical grid to adequately represent extreme events in the vicinity of the USEPA Preliminary Site Perimeter.” However, more of the floodplain should have been included in other portions of the model grid to correctly represent the flows throughout the estuarine system during the extreme floods simulated during the 21-year model simulation, *e.g.*, the October 1994 flood. The 100-year floodplain was represented in the LTFATE model grid.

Two-Dimensional depth averaged model. It states in Section 2.3 of Anchor QEA (2012) that “the two-dimensional, depth-averaged hydrodynamic model within EFDC was used, which is a valid approximation for the nonstratified flow conditions that typically exist in the San Jacinto River”. No salinity data are presented to support this assumption. Stating that models of other estuaries in Texas have used depth-averaged hydrodynamic models is not an acceptable technical justification for this assumption.

Use of hard bottom in the HSC and in the upper reach of the SJR. Regarding this issue, EPA commented that “a justification for assuming the sediment bed was hard bottom in the SJR channel downstream of Lake Houston Dam and in the HSC shall be added to the report. How far downstream in the river channel was a hard bottom assumed? In addition, the report shall comment on potential impacts of these assumptions on sediment and contaminant transport processes in proximity to the Superfund site." In response, the following text was added to Section 4.2.2:

> ".. the numerical grid was extended up to Lake Houston for hydrodynamic purposes (*i.e.*, to ensure that the tidal prism of the San Jacinto River is properly represented in the model). The sediment bed was specified as hard bottom in this portion of the San Jacinto River because: 1) no significant dioxin bed sources exist within this region (see Section 5.2.5.2); and 2) sparse data were available for specifying bed properties (*i.e.*, there is a large uncertainty in bed type and composition). Thus, specification of the sediment bed in the San Jacinto River channel between the dam and Grennel Slough as cohesive or non-cohesive (*i.e.*, erosion and deposition fluxes were calculated) was not necessary to meet the objectives of this study." This justification seems technically justifiable. However, the discussion of sensitivity analyses results along the San Jacinto River does not take into account the hard bottom assumed for this river between the Lake Houston dam and Grennel Slough. For example, in the second paragraph of Section 5.3.3.2.1 it states "due to flux from sediments [porewater diffusion and erosion]". These processes do not occur to a hard bottom. The appropriate portions of Section 5.3.3.2.1 should have been rewritten (as stated in two previous reviews of this report) to account for the fact that, for example, porewater diffusion, sediment bed mixing, and erosion do not occur in the hard bottom reach. In addition, the procedure used to make "slight adjustments .. to the water column concentrations during calibration to avoid "double counting" of contaminant inputs" needs to be more thoroughly described.

Regarding the hard bottom assumption for the Houston Ship Channel (HSC), the report states the following:

> "With respect to the HSC, specifying the sediment bed as hard bottom was valid because sufficient data were available to specify water column chemical concentrations within the HSC (see Section 5.2.3). It is not necessary to simulate erosion and deposition processes in the HSC because water column chemical concentrations in the HSC can be specified using data, which is all that is necessary for the chemical fate and transport model. Simulating erosion and

> deposition fluxes within the HSC would not have improved the predictive capability of the chemical fate and transport model within the USEPA Preliminary Site Perimeter."

These explanations are not justifiable, at least not without quantifying the effects of this assumption using a sensitivity analysis. It states that water column chemical concentration data are available for the HSC. Are there data for all 21 years of the model simulation? While the assumption that "simulating erosion and deposition fluxes within the HSC would not have improved the predictive capability of the chemical fate and transport model within the USEPA Preliminary Site Perimeter" may be valid, a sensitivity test should have been run to quantitatively justify this assumption.

Delineation of the sediment bed. It states in Section 4.2.2 of Anchor QEA (2012) that the sediment bed in a given area was specified as cohesive if the median particle diameter, D_{50}, is less than 250 μm and if the combined clay and silt content is greater than 15 percent. Unless the fraction of clay size sediment is the majority of the combined clay and silt content, it is unlikely if sediment with only these two criteria are cohesive in behavior. More justification needs to be given to support this assumption as it would definitely have an impact on the erosion and transport of sediment in the SJR estuary.

Calibration of the hydrodynamic model. The comparison of measured and simulated depth-averaged velocities shown in Figures 3-23 – 3-25 indicates that the model is under predicting the maximum velocities during both ebb and flood tides, but more so during the latter. In particular, the poor agreement seen during the period July 3 – 4 indicated the model did not accurately represent the combined tidal and riverine flows during this high flow event. The impact that the location of the downstream boundary in the AQ model had on these comparisons is not known. This will be investigated using the LTFATE model. Based on these comparisons of the simulated versus measured velocity times series, I do not completely agree with the last sentence in this section that states 'the calibration and validation results demonstrate that the model is able to simulate the hydrodynamics within the Study Area with sufficient accuracy to meet the objectives of this study'.

Calibration of the sediment transport model. How were the two qualitative conclusions made in the last two sentences of the fourth paragraph of Section 4.3 ("Overall, the model predicts net sedimentation with reasonable accuracy' and 'The general pattern of net sedimentation is qualitatively consistent with known characteristics of the Study Area') arrived at? I come to a different conclusion when examining the comparisons shown in Figs. 4-24 and 4-25, especially for two of the three stations within EPA's Preliminary Site Perimeter. It seems that the model does not predict net sedimentation with reasonable accuracy. My conclusion remains the same even after reading the discussion of the effect of spatial scale on model results in the last paragraph in Sec 4.5. Finally, what are the known characteristics of the Study Area that mentioned in the last sentence?

Other factors/processes not represented in the modeling. These include the following: wind waves and the effects of barges and prop wash on sediment resuspension at the Site. The text that was added to Section 4.1 of Anchor QEA (2012) explaining why wind-wave resuspension is not simulated is valid for non-storm conditions. However, it should have been evaluated in the sensitivity analysis for simulated storm conditions. Regarding the effects of barges and prop wash, it is noted that AQ commented that "The potential effects of ship and barge traffic on sediment transport within the USEPA Preliminary Site Perimeter will be evaluated during the Feasibility Study."

Model Evaluation – Hydrodynamic Model

The AQ hydrodynamic model for the SJR was benchmarked for model output integrity and reliability. These verification and benchmarking tasks were intended to ensure that the hydrodynamic model correctly simulates the riverine and estuarine circulation in the SJR estuary. The evaluation consisted of the following three steps:

1. Model inputs were reviewed to verify consistency with what is documented in Anchor QEA (2012). As a component of this, model-data comparisons were performed for the hydrodynamic input files to insure that the correct parameterizations were used in the model.

2. Model output integrity was verified for selected simulations by recompiling the AQ source code, re-running these simulations with the generated executable, and comparing the model results from these simulations to the model results provided by AQ.

3. Verification of model calculations was accomplished by reviewing model outputs. This review focused on model calculations that were specific to the SJR model domain.

<u>Verification of Model Inputs</u>

Model inputs for bathymetry, inflows, and downstream tidal boundary conditions are based on site-specific data. The goal of the review was to insure the inputs were correctly specified in the model input files. All the hydrodynamic input files were checked, and no problems were identified. Specifically, the input files which described the computational grid were checked to insure the SJR model grid was correctly represented, and the bathymetric data included in the files were correct. Selected model simulation input files, including flow and stage boundary condition files, were also checked for consistency. No inconsistencies were found during these checks, so the model inputs for the hydrodynamic model were successfully verified.

<u>Verification of Model Calculations</u>

The hydrodynamic model for the SJR is based on the EFDC model, which is an open source model supported by EPA Region 4, and which has been applied to many rivers, estuaries, other water bodies worldwide. The AQ version of EFDC was compiled on a Windows computer using the FORTRAN Compiler for Windows by Intel and on a Linux server using the Intel FORTRAN Compiler for LINUX. These recompilations were performed to verify that the AQ version of EFDC could be successfully compiled on different computers using different operating systems (*i.e.*, Windows and Linux). The results obtained using the code executable received from AQ were identical (to within machine precision) with the results obtained using the two recompiled codes. The recompiled code run on the Windows computer was run in full debug mode, but no runtime errors occurred. The conclusion from this task is that the AQ version of EFDC was successfully verified.

Benchmarking of Model Outputs

The 21-year hydrodynamic model simulation was benchmarked to insure that model outputs provided by AQ were reproduced. This simulation was performed using the recompiled code on a Windows computer. The 21-year simulation was successfully completed without any runtime errors, and comparisons of the output from this simulation with that produced using the code executable provided by AQ were identical (to within machine precision). The conclusion from this task is that the AQ version of EFDC was successfully benchmarked.

Model Evaluation - Sediment Transport

The AQ sediment transport model was benchmarked for model output integrity and reliability. These verification and benchmarking tasks were intended to ensure that the sediment transport model correctly simulates the represented sediment transport processes. The evaluation consisted of the following three steps:

1. Model inputs were reviewed to verify consistency with what is documented in Anchor QEA (2012). As a component of this, model-data comparisons were performed for the sediment transport input files to insure that the correct parameterizations were used in this model.

2. The model output integrity was verified for selected simulations by recompiling the AQ source code, re-running these simulations with the generated executable, and comparing the model results from these simulations to the model results provided by AQ.

3. The verification of model calculations was accomplished by reviewing model outputs. This review focused on model calculations that were specific for the SJR modeling system.

Verification of Model Inputs

The following sediment transport model inputs are based on site-specific data, and should be consistent across all model simulations.

- Effective particle diameter for each size class
- Cohesive resuspension parameters (τ_{cr}, A, n)

- *D90* (used for skin friction calculation)
- *D50* (used for initial grain size distribution calculations, as well as other sediment transport calculations)
- Initial grain size distribution
- Dry bulk density

The verification of model inputs for the sediment transport model used consisted of the following components:

1. The values used for the input parameters listed above were reviewed to insure they were within the expected ranges, *i.e.*, ranges of these parameters reported in the literature. The values of all these model inputs used in the sediment transport modeling fell within the expected ranges and/or were the same as given in Anchor QEA (2012).

2. All of the input files for the sediment transport model were checked to verify that the values of the parameters listed above were consistently used. This check revealed that the same values were used for these parameters in all the input files.

3. The time series of solids loading for the sediment transport model were plotted using the model input time series to identify any unusual or outlying solids load inputs. No problems were noted, and the time series were as described in Anchor QEA (2012).

In conclusion, no inconsistencies or incorrect values were found during these checks, so the model inputs for the sediment transport model were successfully verified.

<u>Verification of Model Calculations</u>

The various processes and rate calculations included in the sediment transport model (*e.g.*, settling speed, probability of deposition, resuspension rate) all feed into the computation of the erosion and deposition fluxes for each particle size class in each grid cell at every model time step. Along with velocity and water surface elevation time series for every grid cell that are calculated by the hydrodynamic model, calculated time series of the erosion and deposition fluxes along with the resulting time series of water column concentrations of suspended sediment in every grid cell are passed to the contaminant transport and fate model. These hydrodynamic and sediment transport time series are used to drive the contaminant model. Considering that the transport and fate of highly hydrophobic chemicals (such as PCBs) that are mostly sorbed to particulate organic matter (POM), and that varying fractions of POM are typically adsorbed to sediment particles, in particular clay and silt size particles, the fate of hydrophobic chemicals are typically governed to a significant degree by the transport and fate of these solids. As such, verification of the calculations of erosion and deposition fluxes of solids in the model is essential.

The calculations of the sediment transport model were checked using the following two tasks:

1. The model code was reviewed to verify that the sediment transport model computes erosion and deposition fluxes correctly.

2. Values of the following parameters and variables that were used in the calculation of erosion and deposition fluxes were printed out during a model run to verify that correct values for the parameters being used in the calculations and that variables (*e.g.*, near-bed suspended sediment concentration) were being calculated correctly.

   a. Deposition flux components: settling speeds of the sediment size classes, probabilities of deposition, and near-bed suspended solid concentrations.

   b. Erosion flux components: critical shear stresses, erosion rate for the non-cohesive solid classes, and the erosion rate for the cohesive size class.

The finding from the first task was that the model code was correctly calculating the specified erosion and deposition fluxes, and the findings from the second task were that a) the correct parameter values were being used, and b) the correct values of relevant variables were being calculated by the model. Therefore, the conclusion from this task is that the sediment transport related calculations performed by AQ's sediment transport model were successfully verified.

<u>Benchmarking of Model Outputs</u>

The 21-year sediment transport simulation was benchmarked to insure that model outputs provided by AQ were reproduced. This simulation was performed using the recompiled code on a Windows computer. The 21-year simulation successfully finished without any runtime errors, and comparisons of the output with that produced using the code executable provided by AQ were identical (to within machine precision). The preliminary conclusion from this task is that the AQ sediment transport model was successfully benchmarked.

2. Application of LTFATE

Model Setup

Model Domain

The model domain (highlighted in blue) chosen for LTFATE is shown in Figure 2-1. As seen, the downstream boundary is adjacent to Morgan's Point, and includes the 100-year floodplain (FEMA designated floodway zone) as indentified by FEMA.

Model Grid

Figures 2-2 and 2-3 show zoomed in views of the orthogonal curvilinear model grid in proximity to the Site and the downstream boundary at Morgan's Point. The average grid sizes at the Site and at the downstream boundary are 18m by 18m and 50m by 65m, respectively. The average deviation angle from orthogonal for the entire grid is 3.7 degrees, which is acceptable and insures that mass loss of water and transported constituents due to too large a degree of non-orthogonality does not occur.

Bathymetry Data

The same bathymetry data used by AQ (as documented in Appendix A in Anchor QEA (2012) were used in constructing the LTFATE grid.

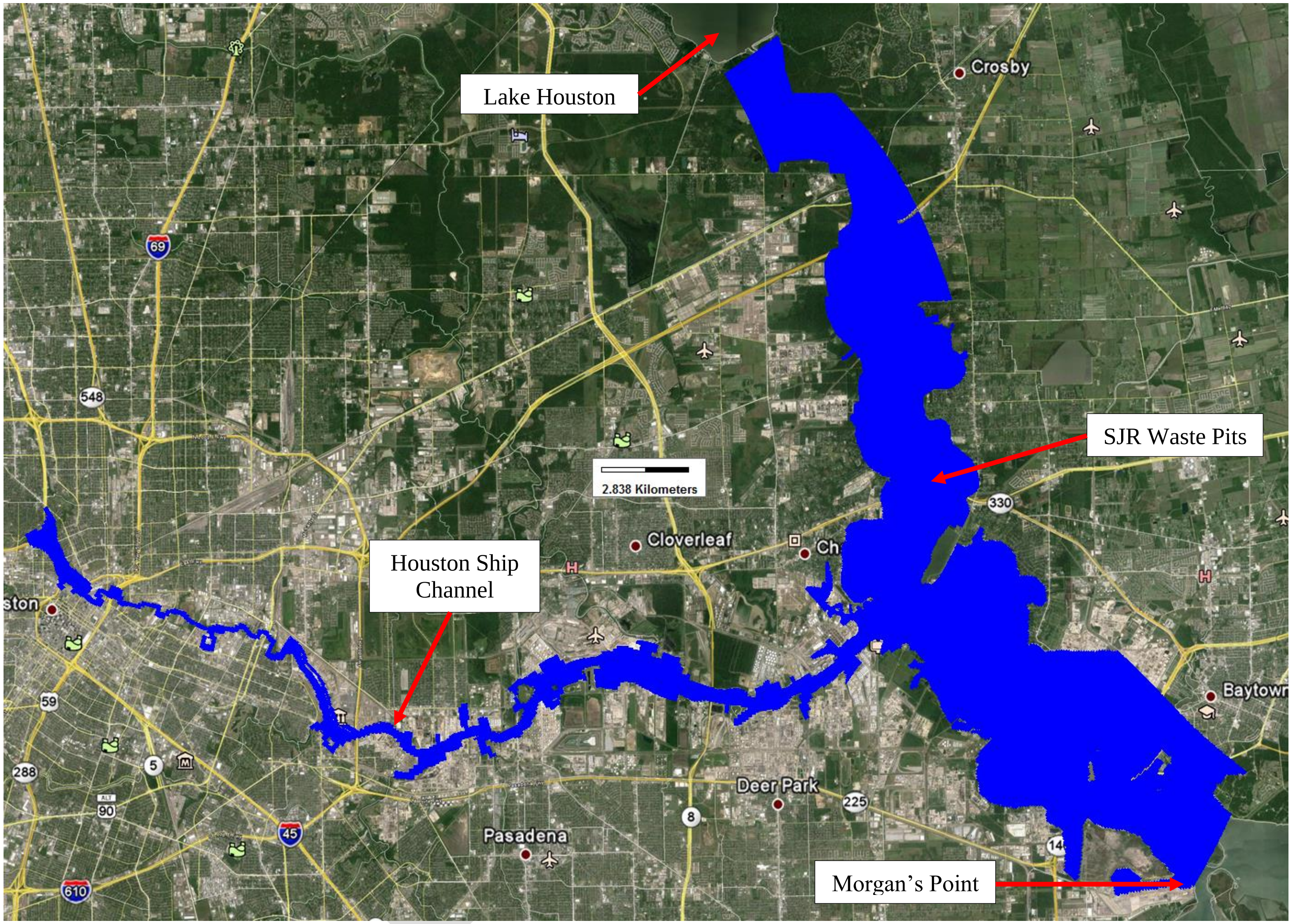

Figure 2-1 LTFATE San Jacinto River Model Domain

Figure 2-2 Grid in Proximity to the SJR Waste Pits Site

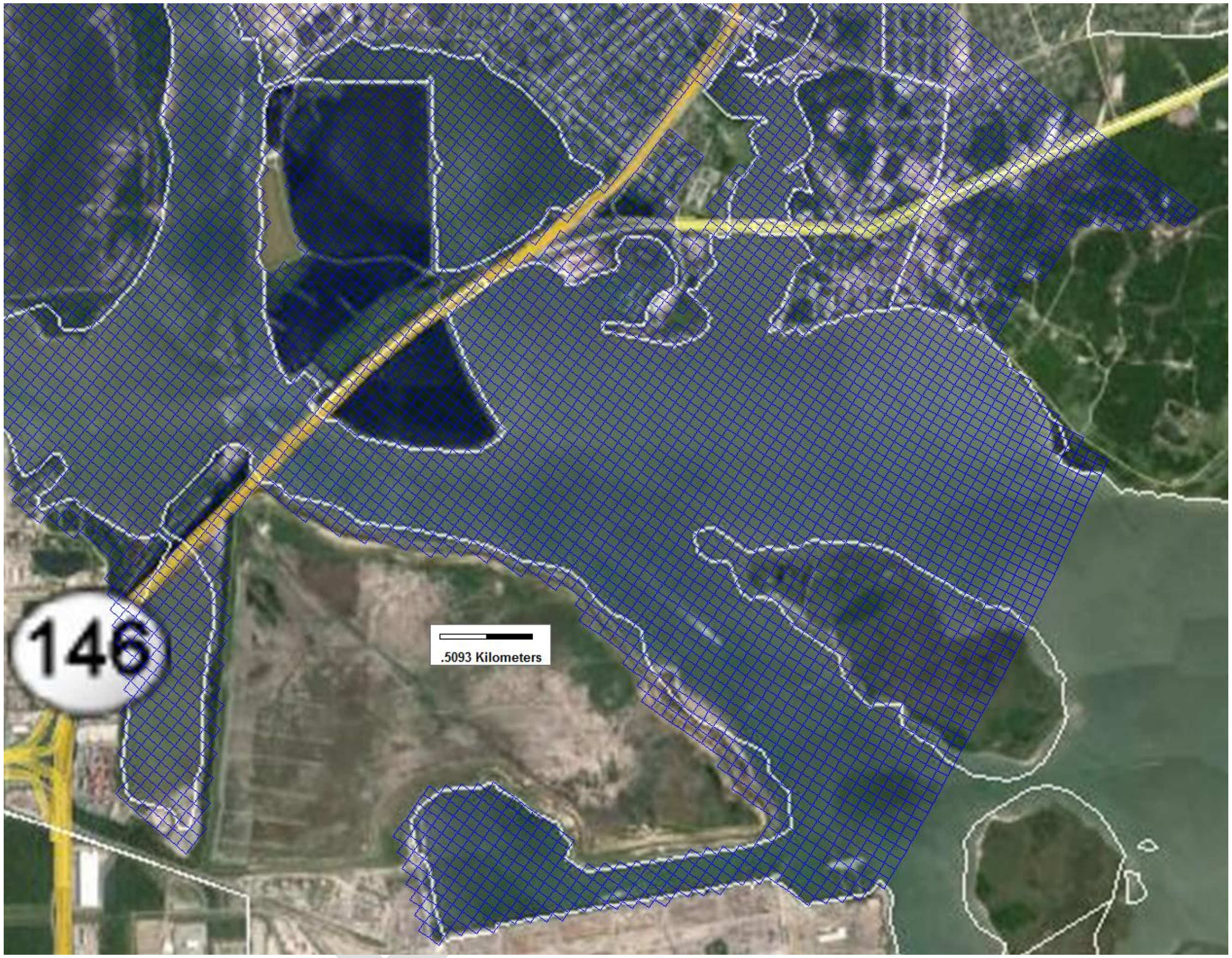

Figure 2-3 Grid in Proximity to the Downstream Boundary

Boundary Conditions

The same boundary conditions used by AQ in their hydrodynamic and sediment transport models were used in LTFATE. The measured water surface elevations at the NOAA tidal station at Morgan's Point were applied to all the wet cells across the downstream open water boundary. The same salinity boundary conditions are used as were used by AQ. Due to the lack of salinity data over the water depth at the downstream boundary, the LFATE model was run in a two-dimensional, depth-averaged mode like AQ's model.

Initial Sediment Bed

In specifying the initial sediment bed, the same four sediment size classes that AQ used were used in the SEDZLJ module in LTFATE. One difference between AQ's version of SEDZLJ and that used in LTFATE is that in the latter, the grid cells are not defined as being either cohesive or noncohesive and then not allowed to change during the model simulation as in the AQ version. In the LTFATE version, whether the surficial sediment is cohesive or noncohesive in behavior is determined for every active (*i.e.*, wet) grid cell during each time step. This enables the changing nature of natural sediment beds due to the varying composition of suspended sediment as well as sediment being transported as bedload to be represented. It was assumed that floodplain cells have an initial hard bottom, *i.e.*, they cannot erode. However, sediment is allowed to deposit on inundated floodplain cells, and the deposited sediment is allowed to resuspend if the bed surface of these cells is subjected to a high enough bed shear stress while the floodplain cell is wet. This is also different from the methodology used by AQ as their model does not allow sediment being carried in suspension to deposit on cells (whether they are floodplain or wet cells) that have a hard bottom.

Model Debugging

To insure that both the hydrodynamic and sediment transport modules in LTFATE were setup correctly, the model was run in full debug mode (Using the Intel FORTRAN compiler) for three days. The reason that it was run for only three days is that the compile code runs much slower in debug mode than it does in optimized mode.

Simulated Processes

The differences between LTFATE and AQ's sediment transport model are the following: 1) Bedload transport is simulated in LTFATE but not in AQ's sediment transport model; 2) The effect of bottom slope on bedload transport and erosion rates is accounted for in LTFATE but not in AQ's sediment transport model. The methodology described by Lick (2009) to include the effect of bed slope on erosion rates and bedload transport is incorporated in the LTFATE version of SEDZLJ. The bed slopes in both the x- and y-directions are calculated, and scaling factors are applied to the bed shear stress, erosion rate, and bedload transport equations. A maximum adverse bed slope is specified that prevents bedload transport from occurring up too steep an adverse slope.

Calibration of the Hydrodynamic and Sediment Transport Models

The same data sets used to calibrate the AQ hydrodynamic model (ADCP surveys conducted June 13 – July 7, 2010 and May 10 – July 13, 2011) were used to calibrate LTFATE. To date, the optimum agreement in the simulated and measured water levels and depth-averaged velocities was achieved using a globally averaged value of 0.1 cm for z_0 = effective bed roughness that represents to total bottom roughness due to both skin friction and form drag. The RMS error in the water surface elevations for the 2010 and 2011 periods were 4.25 cm and 4.75 cm, respectively. The RMS error in the depth-averaged velocities for the 2010 and 2011 periods were 0.12 m/s and 0.11 m/s, respectively. Efforts to decrease these RMS errors are continuing. Likewise, the same data AQ used to calibrate their sediment transport model is being used to calibrate LTFATE, with the main metric being the net sedimentation rate. The calibration of the sediment transport model in LTFATE cannot be finalized until acceptable results are obtained from the hydrodynamic model calibration. The final results from these calibration efforts will be presented in the final report.

Task 4

Statement

Provide an uncertainty analysis of the model assumptions (flow rates, boundary representation, sediment transport, sedimentation rates, initial bed properties, etc.). Uncertainties should be clearly identified and assessed including sediment loads at the upstream Lake Houston Dam.

Findings

It is standard to evaluate the effects of uncertainties in model inputs using a sensitivity analysis. Thus, this task was performed by expanding on the sensitivity analyses performed by AQ with their models. A review of the analysis that AQ performed is given below, followed by a critique of their analysis, and then a description of the expanded sensitivity analysis being performed for this task is given. The completion of the latter task was delayed due to the failure two weeks ago of the computer workstation on which these sensitivity model runs were being performed.

1. AQ Sensitivity Analysis

The sensitivity analysis performed by AQ evaluated the effects of varying input parameters for both the sediment transport model and the hydrodynamic model. These analyses are summarized below.

The sensitivity analysis performed by AQ evaluated the effects of varying the following sediment transport model input parameters: erosion rates, incoming sediment load at the Lake Houston Dam, and the effective bed roughness as quantified by the value of D_{90}. The latter was only increased by a factor of two, whereas the incoming sediment load was varied by $\pm$ 2. Both changes are with respect to the base case simulation. Lower and upper-bound parameters that were based on the erosion rate ratio values for the Sedflume cores, with the lower-bound being Core SJSD010 and the upper-bound being Core SJSF003. AQ evaluated the effects of possible interactions among the three input parameters using a factorial analysis. The latter produced eight model simulations that accounted for all of the possible combinations of the upper and lower bounds of the three parameters. The results of these eight model simulations were compared "using the sediment mass balance for the Study Area as the metric for quantitative comparison". Figure 4-44 in Anchor QEA (2012) shows the predicted sediment mass balance for the entire model domain over the 21-year model simulation, and the trapping efficiency was determined to be 17 percent. Trapping efficiency is calculated as the percentage of the incoming sediment load that is deposited in the model domain. Seven of the eight sensitivity simulations had positive trapping efficiencies, *i.e.*, they were net depositional over the 21-year simulation period, whereas one of the simulations was net erosional so no trapping efficiency was calculated for that simulation. The seven positive trapping efficiencies ranged from 6 to 24 percent (see Figure 4-49 in Anchor QEA (2012)). AQ also presents comparisons of the gross erosion rate, the gross deposition rate, and the rate of net change for the entire model domain and the Site Perimeter, respectively, in Figures 4-50 and 4-51 for the base case and eight sensitivity simulations. Their findings from these sensitivity simulations were the following: 1) Changes in the upstream sediment load had the largest effect on the net deposition over the 21-year simulation; and 2) The effects on both net erosion and net deposition due to the variations in erosion rate parameters and the effective bed roughness were of similar magnitude, and most importantly, were significantly less than the effect from varying the incoming sediment load from Lake Houston.

The sensitivity analysis performed by AQ evaluated the effects of varying the following hydrodynamic model input parameters: channel bathymetry in the vicinity of Grennel Slough, water inflow at the Lake Houston Dam, salinity at the downstream boundary, and the water surface elevation (WSE) at the downstream boundary. The effects of these input parameters on both the hydrodynamic and sediment transport models were determined by simulating conditions for 2008 (during which Hurricane Ike occurred) for both the base case (using the original input parameters) and the sensitivity model runs. The differences between the base case and the different sensitivity runs were quantified by determining the differences in bed elevation changes within the Site Perimeter at the end of the one-year model simulations. Results from this analysis are described next.

The channel bathymetry in the vicinity of Grennel Slough was modified by eliminating two areas that created a cutoff in the channel due to spatial interpolation of the bathymetric data. Analysis of the model simulation of 2008 found that the original bathymetry that contained the two cutoffs had negligible effect on the hydrodynamics and sediment transport within the Site.

As discussed in Anchor QEA (2012), the water releases at the Lake Houston Dam were estimated for the period of the 21-year simulation prior to July 1996. The impact of the method used to estimate the inflows into the SJR on the model results was evaluated by using the same method to estimate the inflows for 2008 and running the models for that year. The results from this analysis revealed that the method used for estimating the inflows prior to July 1996 had relatively minor effects on the sediment transport simulations within the Site perimeter.

A constant salinity of 16 psu was used at the downstream boundary for the 21-year simulations. The effect of the salinity value used for the downstream boundary on sediment transport simulations at the Site was investigated by simulating 2008 using both a salinity boundary condition of 16 and 0 psu. These two simulations were compared and negligible impacts on the sediment transport results were found. This is not a surprising result when using a depth-averaged model.

The effect of the WSE used at the downstream boundary was investigated in the following manner. The year 2002 was simulated using the WSE obtained from data collected at the Morgan's Point tidal gauge station as well as using the WSE data collected at the Battleship Texas State Park/Lynchburg station. The bed elevation changes for each grid cell within the Site Perimeter were compared between these two model simulations, and minimal differences were found. Thus, AQ concluded that the WSE data used at the downstream boundary in their model did not have a significant impact on the sediment transport results in proximity to the Site.

2. Critique of the AQ Sensitivity Analysis

Overall, the sensitivity analysis performed by AQ is the best method for attempting to put bounds on the uncertainty in results obtained from any transport and fate modeling study. The use of trapping efficiency as a metric for quantifying the results from the sensitivity analysis is thought to be somewhat limited in its usefulness. However, the finding that the largest source of uncertainty in the sediment transport modeling is the estimated sediment loading from the Lake Houston Dam is not surprising.

As the USGS commented in their review, "to improve the model, better sediment load information from Lake Houston Dam is necessary." However, having more accurate sediment loading data may or may not improve the model's ability to predict sediment transport in the SJR estuary. This same thought is conveyed in USGS's comments 29 and 37.

It is the opinion of the PDT that the largest source of uncertainty is the application of a model framework that does not account for morphologic feedback between the sediment transport and hydrodynamic models to a water body such as the SJR. The SJR estuary is subjected to aperiodic large hydrologic events, *i.e.*, floods and hurricanes, such as the three significant events that occurred during the 21-year simulation period, during which significant sediment transport and large scale scour and sedimentation occurred in certain portions of the estuary. The unquantified uncertainty in applying a non-morphologic modeling system to such a system limits the usefulness of the sensitivity analysis performed using the non-morphologic models. In addition, the other issues discussed in Task 3, *e.g.*, inclusion of the 100-year floodplain in the model grid, location of the downstream boundary, definition used to classify sediment as cohesive, use of a hard bottom in the HSC, etc., are believed to further increase the uncertainty in the model results. A better model framework to use at the SJR would have been the one that AQ used in simulating primarily noncohesive sediment transport in the Tittabawassee River, Michigan in which a quasi-linkage routine was added between the sediment transport and hydrodynamic models. In both water bodies, the magnitude of the morphologic changes is within one order of magnitude of the water depths, thus necessitating the linkage between the hydrodynamic and sediment transport models.

3. Expanded Sensitivity Analysis

In an attempt to better quantify the uncertainty associated with the model framework and the other issues listed above and in Task 3, an expanded sensitivity analysis is being performed as a component of this project. It is being performed using the LTFATE modeling system that was setup to represent the SJR estuary model domain. The multiple model simulations are still underway at present, so no results are presented in this first report. The results will be included in the final report. A description of the methodology being used in performing this expanded sensitivity analysis is described next.

The effects of changes in the following parameters on model results are being investigated using a sensitivity analysis approach similar to the factorial analysis methodology used by AQ with the LTFATE modeling system:

- Simulation of bedload
- Different classification of cohesive sediment
- Sediment loadings at the Lake Houston Dam
- Use of a non-hard bottom in the HSC

Table 2-1 lists the nine sensitivity simulations that have been setup and tested to insure there are no runtime errors for the different parameterizations. Run 1 represents the Base Case. Each of these sensitivity runs is for the September – October 1994 time period. The inclusion of the 100-year floodplain in the model grid and the use of the dynamically linked hydrodynamic model and sediment transport model option are being used in all nine sensitivity simulations.

Table 2-1
Sensitivity Simulations

Sensitivity Run	Bedload Simulated	Different cohesive sediment classification	Inflow sediment loadings	Hard bottom in the HSC
1	No	No	AQ	Yes
2	No	Yes	AQ	Yes
3	No	No	Upper Bound	Yes
4	No	No	Lower Bound	Yes
5	No	No	AQ	No
6	Yes	No	AQ	Yes
7	Yes	Yes	AQ	Yes
8	Yes	Yes	AQ	No
9	Yes	Yes	Upper Bound	No

Task 5 and Task 6

Statements

Perform a technical review of the design and construction of the entire existing cap as it is currently configured. Identify any recommended enhancements to the cap.

Assess the ability of the existing cap to prevent migration of dioxin, including diffusion and/or colloidal transport, through the cap with and without the geomembrane/geotextile present.

Findings

Background

Design and construction of the existing TCRA cap was divided into three sections, each of which has different cap components. The Western Cell is generally above the water line; the Eastern Cell is mostly covered with less than 5 ft (1.5 m) of water; and the Northwestern Area is mostly in greater than 10 ft (3.0 m) of water. The Western Cell cap is composed of a geotextile filter, a geomembrane, a protective geotextile cushion and armor stone. The Eastern Cell has a geotextile filter and armor stone. The Northwestern Area has predominantly granular filter blended with armor stone. These three sections were further subdivided into subsections with varying armor stone. The cap is presently built with some slopes steeper than 1V:3H. The thicknesses of the armor stone is at least twice the D_{50} of the stone. The armor stone is sized for limited movement during storm events having a return period of up to 100 years. The capped sediment consists predominantly of a soft, compressible, organically rich sludge.

Western Cell

The Western Cell should largely be physically stable provided that all surfaces have a slope flatter than 1V:3H, all areas of potential high bottom shear stress with a slope steeper than 1V:5H are covered in natural stone, the bottom shear stresses are properly modeled, and no significant localized deformations occur to disrupt the geomembrane. Soft sediments were solidified/stabilized prior to cap construction. The design and construction followed standard practice for land-based operations. The geotextiles were overlapped and geomembrane seams were welded. The armor stone, geotextiles and geomembrane effectively isolates environmental receptors from the contaminated sediment. The geotextiles used in the design provide adequate protection for the geomembrane to prevent puncture and to provide long-term chemical isolation. The geomembrane will control infiltration, seepage and tidal pumping along with their associated dissolved and colloidal transport of contaminants. The geomembrane also controls diffusion and resuspension, effectively isolating the contaminants. No groundwater transport in the sediment under the cap across the site is anticipated based on the topography of the region, location of the site, and permeability of the sediment. Flattening of some steeper slopes is recommended to increase the factor of safety and provide for long-term stability.

Eastern Cell

The Eastern Cell should largely be physically stable provided that all surfaces have a slope flatter than 1V:3H, all areas of potential high bottom shear stress with a slope steeper than 1V:5H are covered in natural stone, the bottom shear stresses are properly modeled, and no significant localized deformations occur to disrupt the geotextile. The design and construction followed standard practice for water-side operations. The geotextiles were overlapped and secured in place during placement of the armor cap. The geotextiles were rolled out and advanced gradually during armor cap placement to maintain their positioning. The armor stone and geotextile effectively isolates environmental receptors from the contaminated sediment. The Eastern Cell does not contain a geomembrane to control resuspension and the advective and diffusive fluxes of contaminants. However, being submerged and relatively flat without regional surficial groundwater upwelling, no significant advective flux is anticipated to provide transport of dissolved or colloidal contaminants. A small quantity of porewater with dissolved and colloidal contaminants would be expelled in the short term through the cap from consolidation and compression of the sediment under the pressure loading imposed by the armor cap. This contaminant mass loss is very small compared to the resuspension losses prior to capping, but likely to be several times greater than the diffusive losses during the same period. Resuspension of contaminated particles is not expected because the geotextile will provide a filter to control particle movement and prevent translocation of the capped sediment to the surface. Therefore, contaminant transport would be restricted to porewater expulsion and diffusion. The diffusive flux of contaminants from the capped area is very small compared to resuspension losses of contaminated particulates prior to capping; however, the diffusive losses from the sediment are largely unimpeded by the cap. The armor cap material does not have a significant quantity of organic carbon to retard contaminant transport. In addition, the large pore structure of the armor cap material would permit a large exchange of water within the cap, preventing the formation of a concentration gradient to slow the diffusion. Addition of an amendment like AquaGate™ or SediMite™ could further reduce the potential contaminant losses from diffusion. A product like AquaGate™ would also provide added protection from erosion by providing cohesion between granular particles and filling the pores of the Armor Cap C and D materials, and perhaps also the recycled concrete of the Armor Cap A and B/C materials.

Northwestern Area

The design and construction of the cap in the Northwestern Area is very different than the other two cells and does not provide the same level of confidence in its long-term stability and performance. The area is largely capped with twelve inches of non-uniform recycled concrete blended with granular filter material at a ratio of 4:1. The D50 of the recycled concrete was specified to be 3 inches (7.6 cm). Slopes within the Northwestern Area are as steep as 1V:2H. The cap was placed in layers proceeding from deep water to shallow water, following standard construction practices for water-side operations.

Placement of recycled concrete with a blended filter on slopes steeper than 1V:3H, and perhaps as flat as a 1V:5H slope, promotes separation of the sand-sized particles and perhaps gravel-sized particles from the larger concrete particles. The finer particles would have a tendency to run down the slope, coarsening the cap on the upper portion of the slopes and reducing the effectiveness of the filter on the upper slope. Without a filter being placed on soft sediments (having low bearing capacity) prior to placement of the armor material, the larger particles of recycled concrete would embed themselves in the sediment and promote mixing of the cap with the sediment, thereby limiting the isolation of the sediment. Use of a blended filter would tend to be less effective on very soft sediments than a separate granular filter. To ensure physical stability of the cap, the cap and blended filter should be placed on a slope no greater than 1V:3H, and preferably 1V:5H.

Mixing of the sediment with the capping media and inadequate filtration due to loss of the finer fraction of the capping media (sands and perhaps gravel) due to separation during placement may allow losses by resuspension in addition to diffusion and porewater expulsion. Additionally, bioadvection of sediment may translocate sediment particles to the surface where the sediment can be resuspended. Burrowing to a depth of 12 to 15 inches (30.5 to 38.1 cm) may be expected in the absence of a geotextile or a geomembrane. Thickening the cap in the Northwestern Area would virtually eliminate the potential resuspension losses.

Regardless of whether resuspension losses occur, there are potential contaminant losses by diffusion, porewater expulsion, tidal pumping and groundwater seepage. Like the Eastern Cell, the Northwestern Area does not contain a geomembrane to control the advective and diffusive flux of contaminants. However, being submerged and relatively flat without regional surficial groundwater upwelling, no significant advective flux by groundwater seepage is anticipated to provide transport of dissolved or colloidal contaminants. A small quantity of porewater with dissolved and colloidal contaminants would be expelled in the short term through the cap from consolidation and compression of the sediment under the pressure loading imposed by the armor cap. This contaminant mass loss is very small compared to the resuspension losses prior to capping, but likely to be several times greater than the diffusive losses during the same period. Therefore, contaminant transport is restrictive to porewater expulsion and diffusion. The diffusive flux of contaminants from the capped area is very small compared to resuspension losses of contaminated particulates prior to capping; however, the diffusive losses from the sediment are largely unimpeded by the cap. The armor cap material does not have a significant quantity of organic carbon to retard contaminant transport. In addition, the large pore structure of the armor cap material would permit a large exchange of water within the cap by tidal pumping, preventing the formation of a concentration gradient to slow the diffusion. Addition of an amendment like AquaGate™ or SediMite™ could further reduce the potential contaminant losses from diffusion by the addition of activated carbon to sequester the contaminants and restrict the exchange of water within the cap. The activated carbon could provide *in situ* treatment of sediment particles mixed into the cap during placement or bioadvected after placement, limiting resuspension losses as well as diffusive and advective losses from the cap. A product like AquaGate™ would also provide added protection from erosion by providing cohesion between granular particles and filling the pores of the recycled concrete of the Armor Cap A material.

Task 7

Statement

Assess the long-term reliability (500 years) of the cap under the potential conditions within the San Jacinto River, including severe storms, hurricanes, storm surge, subsidence, etc. Include in the assessment an evaluation of the potential for cap failure that may result from waves, prop wash, toe scour and cap undermining, rock particle erosion, substrate material erosion, stream instability, and other potential failure mechanisms. Reliability will be based on the ability of the cap to prevent any release of contaminated material from the Site. Also discuss any uncertainty regarding the long-term reliability and effectiveness of the existing cap.

Findings

The methodology being used to assess the long-term reliability of the cap is given below.

1) Evaluate bed shear stresses generated by combining the driving forces resulting from the October 1994 flood and Hurricane Ike.

2) Estimate the erosion potential resulting from the time series of these current- and wave-induced bed shear stresses.

3) To evaluate potential scour of the cap due to prop wash generated by ship traffic in proximity to the cap the following methodology will be used: a) information on ship traffic (*e.g.*, average ship power, size, draft, propeller(s) diameter and type (*i.e.*, ducted or non-ducted), ship speed) must be supplied to ERDC; b) an empirical propwash relationship will be developed and implemented using available ship information; c) calculate the bed shear stress using the method given by Maynord (2000); and d) calculate potential bed erosion using the method given by Maynord (2000). This information has not yet been supplied to the ERDC project team.

4) The following events will also be evaluated as part of the assessment of the long-term reliability:

a. Cap undermining caused by toe erosion.
b. Erosion of the cap cause by movement of the armor rock across the surface of the cap during a large flood and the possible erosion of the substrate material below the cap.
c. Changes in river flow dynamics and channel morphology during a high flow event caused by a major flood or hurricane.

As reported to the EPA RPM, a major setback happened about two weeks ago. The computer workstation the multiple long-term simulations and sensitivity tests had been running on for more than one month had a 'catastrophic failure'. The Dell technician decided it could be restored, and at a minimum the hard drive needs to be reformatted and the OS reinstalled. The computer was shipped back to Dell on February 20. As of February 26, they were still working on it. Since the multiple simulations had been running for more than one month, I had not been able to back up the hard drive since mid-January. When I get the computer back for Dell some day this week, I am going to have to reconstruct those simulations and start the model runs again. At this time, I do not have an estimate for the completion date of this task.

Task 8

Statement

As part of the cap reliability evaluation, assess the potential impacts to the cap of any barge strikes/accidents from the nearby barge traffic.

Findings

It is standard

Task 9

Statement

Identify what institutional/engineering controls (*e.g.*, deed restrictions, notices, buoys, signs, fencing, patrols, and enforcement activities) should be incorporated into the remedial alternatives for the TCRA area and surrounding waters and lands.

Background

The site consists of several waste ponds, or impoundments, approximately 14 acres in size, built in the mid-1960s for the disposal of paper mill wastes as well as the surrounding areas containing sediments and soils potentially contaminated by the waste materials that had been disposed in these impoundments. The impoundments are located immediately north and south of the I-10 bridge and on the western bank of the San Jacinto River in Harris County, Texas (Figure 1-1).

Large scale groundwater extraction has resulted in regional subsidence of land in proximity to the site, which has caused the exposure of the contents of the northern impoundments to surface waters. A time-critical removal action was completed in 2011 to stabilize the pulp waste material in the northern impoundments and the sediments within the impoundments to prevent further release of dioxins, furans, and other chemicals of concern into the environment. The removal action consisted of placement of a temporary armor rock cap over a geotextile bedding layer and an impermeable geomembrane in some areas. The total area of the temporary armor cap is 15.7 acres. The cap was designed to withstand a 100-year storm event.

The southern impoundments are located south of I-10 and west of Market Street, where various marine and shipping companies have operations (see Figure 1-1). The area around the former southern impoundments is an upland area that is not currently in contact with surface water.

Available Engineering and Institutional Controls

Land Use Controls

Land Use Controls (LUCs) are often used at remediation sites to provide protection from exposure to contaminants. LUCs may be implemented as interim protection at sites where remediation is ongoing, or to manage residual contamination (ITRC 2008). LUCs include both engineering controls (ECs) and institutional controls (ICs). Institutional controls are defined by EPA as "non-engineered instruments, such as administrative and legal controls, that help to minimize the potential for human exposure to contamination and/or protect the integrity of a response action" (EPA, 2010). Engineering controls are physical controls that prevent exposure such as fences, barriers, signage, capping or containment. Both ICs and ECs can be used stand-alone, or can be used in conjunction with other ICs or ECs.

Institutional Controls

There are several categories of ICs, including governmental controls, proprietary controls, enforcement and permit tools, and informational devices. Governmental controls, enforced by state or local government, may include bans on harvesting fish or shellfish, zoning restrictions, ordinances, statutes, building permits, or other restrictions. Zoning may be used by local governments to designate land use for specific purposes. Government ordinances or permits may also restrict or control land uses, and outline specific requirements before authorizing certain activities (*e.g.*, building codes, drilling permit requirements). Some local ordinances place controls on access to or use of certain areas within a property. Groundwater management zones may also be used to prohibit certain groundwater uses (ITRC 2008).

Proprietary controls are based on real property law (EPA 2000). Enforceability of proprietary controls should be evaluated under applicable (state) law. Some proprietary controls are enforceable upon execution, others upon the sale or transfer of property. Examples include easements, covenants, and conservation easements. Easements are rights over the use of another's property, and include negative easements which limit uses that would otherwise be lawful. Access easements are sometimes used to ensure current and future property owners allow property access to operate, monitor, or maintain ECs or ICs. Covenants are agreements between the landowner and others connected to the land. They are typically used to establish an IC when property is transferred to another party. Use restrictions/ statutes/ environmental covenants are state statutes that provide owners of a contaminated property with authority to establish use restrictions. Conservations easements are state statutes that establish easements to conserve property or natural resources. Enforcement and permit tools include permits, administrative orders, and consent decrees which are enforceable by state or federal agencies. Most enforcement agreements are binding on only the signatories and do not bind subsequent owners. Examples include administrative orders which are issued by an environmental regulatory agency directing property owners to perform (or not perform) certain actions. Consent decrees document an administrative or judicial court's approval of the settlement of an enforcement case filed in court. These typically specify actions to be taken (or not to be taken) by the settling parties. Permits are implemented by an environmental regulatory agency and may require compliance with a statutory or regulatory provision that may impact the reuse of the property (ITRC 2008).

Informational devices provide information to the public about risks from contamination and generally are not legally enforceable. Informational devices include deed notices, state registries of hazardous waste sites, and advisories. Deed notices are filed in public land records with the property deed that provide information about potential health risks from contamination left on the property. State registries of hazardous waste sites also contain information about contaminated properties. Some state laws provide that the use of the property cannot be changed without state approval. Advisories warn the public of potential risks associated with using contaminated land surface water or groundwater, generally issued by public health agencies (ITRC 2008).

In addition to the legal mechanisms mentioned above, the Uniform Environmental Covenants Act (UECA) is a model statute that can be adopted into law by each individual state or territory (EPA 2010). The UECA provides legal framework to create, modify, enforce and terminate a valid real estate instrument (environmental covenant or IC) to restrict use of contaminated real estate or impose obligations under state law and precluded the application of traditional common law doctrines that might otherwise hinder the validity or enforcement of ICs adopted under state property law or other mechanisms (ITRC 2008). The UECA provides a legal mechanism to ensure LUCs can be readily found, maintained, and enforced over time.

EPA (2000) suggests layering ICs, using different types of ICs at the same time to enhance protectiveness. Applying ICs in series may help ensure both short- and long-term effectiveness. Using ICs in conjunction with physical barriers (ECs) to limit access is also recommended.

The three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements (EPA 2005).

Fishing advisories, restrictions or bans on fishing (including shell fishing) are typical ICs. Commercial fishing bans are government controls that ban commercial fishing for specific species or sizes of fish or shellfish (EPA 2005). Rather than a complete ban, advisories may be placed on certain locations and types of fishing. Advisories inform the public that they should not consume fish from an area or should limit the number of fish meals consumed over a specific time period. Advisories and bans are usually established by state departments of health and can be administered through signs, pamphlets or other outreach materials. Warning signs should be in the language of the local community including new immigrants, and require periodic inspection and maintenance. Monitoring, enforcement and communication with local or state authorities are required. Consumption advisories are not enforceable controls and may have variable effectiveness (EPA 2005). Surveys of anglers are often helpful to evaluate whether they consume the fish they catch and whether restrictions are effective (ASTSWMO 2009). EPA's Water program compiles a database of fish advisories.

Institutional controls may also be needed to protect the integrity of the remedy. Land use restrictions may be needed at near-shore or upland sites to limit or eliminate construction activities, digging or other activities that may disturb the contaminated materials. A deed restriction or notice may be adequate for an upland property, but for in-water remedies, restrictions may be more difficult due to ownership issues. Nearshore areas can, in some cases, be privately owned out to the end of piers. If privately owned, traditional ICs such as proprietary controls or enforcement tools can be considered. Federal, state and local laws place restrictions on and require permits for dredging, filling, or other construction activities in the aquatic environment. ICs may also be implemented through coordination through existing permitting processes (EPA 2005).

Restrictions on vessel traffic to establish no-wake zones or restrictions against anchoring may be necessary to protect a cap. Restrictions on easements for installation of utilities and other in-water construction may also be needed, and should be placed on navigational charts. Navigational buoys or warning flags can be used to help warn boaters (ASTSWMO 2009). Changing the navigation status of a waterway may also be necessary. Deauthorization or reauthorization of federally authorized navigation channels to a different width or depth would be required. The state may have authority to change harbor lines or the navigation status (EPA 2005).

Management

Application of LUCs require planning to evaluate what types of ICs are appropriate, determine responsible parties for various activities, estimated costs, and issues that may impact effectiveness. When selecting ICs, it should be considered how the controls fit into the overall remedy, and whether it can be realistically implemented. A number of activities may be needed to implement various ICs including drafting and signing documents to establish ICs or arranging technical or legal support (EPA 2010). There may be both short- and long-term expenses associated with implementation and management of LUCs. Some funding mechanisms to cover the cost associated with maintaining and monitoring LUCs include stewardship fees, oversight fees, and trust funds (ITRC 2008).

LUCs require effective management to ensure long-term effectiveness. Both institutional and engineering controls require regular monitoring and maintenance. Enforcement may be needed if ICs are breached or not properly implemented. Enforcement actions vary from state to state, but may include penalties, loss of liability protection, and lawsuits (ITRC 2008). Some states have developed tracking systems to identify LUCs in place, although the nature of the systems varies from state to state. The UECA provides mechanisms for states to develop and maintain a registry of sites with ICs.

More detailed information on institutional controls as applied to Superfund sites, Brownfields, underground storage tanks, federal facilities and RCRA site cleanups is provided by EPA (2005, 2010).

ICs Used at Other Sites

A number of contaminated sediment sites have established institutional controls. At the Lake Hartwell Superfund Site, fish consumption advisories are in effect, and implemented by posting warning signs and distribution of printed material to educate the public (EPA 1994, Magar *et al.* 2009). Fish and/or shellfish advisories are also used at the Lavaca Bay Point Comfort site in Texas (fish and shellfish), Wyckoff/Eagle Harbor (Magar *et al.* 2009), and Marathon Battery Corporation (blue crab) (EPA 2008). At Fox River, Wisconsin, fish advisories are in place to prevent ingestion of PCB-contaminated fish above 50 ppb, along with MOUs to limit anchoring, dredging, dragging, or construction over sediment caps (Tetra Tech *et al.* 2012, Ridenour). At Palos Verdes Shelf, California, a fish advisory is also in place, along with a commercial catch ban for white croaker. Components of the IC plan include public outreach and education, monitoring, and enforcement (EPA 2009, Ridenour).

The Commencement Bay, Nearshore/Tideflats, Tacoma, WA also has fish consumption advisories in place to warn the public about the danger of consuming shellfish, which are relayed by placement of multi-lingual signs. The institutional control plan for the site (Washington State DNR 2007) describes the controls to be put in place as well as the responsibilities of the various entities involved. In addition to shellfish warnings, other ICs specified at Commencement Bay include restrictive covenants, and control of marine vessel navigation and anchoring through the use of no-anchor zones, and waterway navigational markers and signs regarding prohibited activities, vessel size and speed. A system is also in place to notify appropriate entities as to changes in conditions or unauthorized anchorage or trespassing. Restrictions on issuing leases, easements, rights-of-entry and use authorizations are also in place which require notification, and restrict State-owned aquatic land (SOAL) authorizations for commercial shellfish harvest in capped areas. SOAL authorizations are to include terms specifying the provisions of the Consent Decree including prohibited activities such as any activity that alters the cap, piling removal/installation, dredging/excavation and anchoring.

ICs at Pine Street Canal are specified to limit future land use, excluding residential uses and uses involving the care of children, and activities which may interfere with ongoing investigations or might cause recontamination or change hydrogeologic conditions and migration of contaminated groundwater. Excavation greater five feet is prohibited, along with the use of ground water for drinking water purposes or installation of well and any activity that may disturb the integrity of an engineering control (Burlington Land Records 2004).

In addition to the fish consumption advisory for blue crab (recommending consumption of no more than six per week), Marathon Battery Corp. site has established ICs including deed restrictions barring excavation deeper than 15 feet, construction or use of ground water wells, and any activity that may disturb the marsh soil cover (EPA 2008). The institutional controls for Allied Paper, Inc./Portage Creek/Kalamazoo River prohibits construction or use of wells to extract ground water, activities that may disturb the integrity of an engineering control or result in release of hazardous substances, or limit future land use (Michigan DNRE 2010).

Application of ICs and ECs to San Jacinto River Waste Pits Site

General information on ICs at contaminated sediment sites has been provided. The latest draft feasibility study (FS) (Anchor QEA 2014) lists seven potential alternatives for the final remedy including:

- Alternative 1N – No further action,
- Alternative 2N – ICs and Monitored Natural Recovery (MNR)
- Alternative 3N – Permanent cap, ICs, MNR
- Alternative 4N – Partial solidification/stabilization (S/S), permanent cap, ICs, MNR
- Alternative 5N – Partial removal, permanent cap, ICs, MNR
- Alternative 5aN – Partial removal of materials exceeding the protective concentration level (PCL), permanent cap, ICs, MNR
- Alternative 6N – Full removal of materials > PCL, ICs, MNR

Alternatives 4N, 5N, 5aN and 6N involve removal of some, or all, of the existing TCRA cap, which would expose contaminated sediments during construction. For Alternatives 4N, 5N and 5aN, the cap would be reconstructed and improved after either removal or treatment of the sediments in the affected area. Cap improvements are also included for Alternative 3N. Alternative 6N does not include cap reconstruction as it calls for removal of sediments exceeding PCL across the entire TCRA area.

All alternatives except 1N call for implementation of additional ICs. The recommended ICs described in the FS would be used to: alert property owners of the presence of subsurface materials exceeding PCLs, describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required, describe management requirements for any excavated soils or sediment exceeding PCLs, describe the need to restore the armored cap following any disturbance, and establish limitations on dredging and anchoring within the footprint of the armored cap by requesting that the U.S. Coast Guard District Commander establish a regulated navigation area (Anchor QEA 2014).

Some land use controls are already in place. An advisory (ADV-49) is in place regarding consumption of fish and blue crab on the San Jacinto River (Anchor QEA 2014). Controls were implemented at the site with the TCRA armored cap installation, which is itself an engineering control. Also, a perimeter fence was installed around the perimeter of the impoundments, including a second phase of fencing installed across neighboring property to address unauthorized access that had been observed (Anchor QEA 2012). Warning signs, No Trespassing signs and USEPA Project Identification signs were installed as part of the TCRA and remain in place and are subject to ongoing monitoring and maintenance. A series of 29 buoys (25 ball float, and four regulatory) were installed along the perimeter of the Eastern Cell to warn passing vessels to keep out of the SJRWP area; though not specified, it is assumed the buoys were removed post-construction. Fifteen warning signs on steel posts in 3 ft x 3 ft concrete block are posted around the perimeter of the impoundments to be visible to passing vessels.

It appears the existing land-side fencing and warning signs provide sufficient notification and access control. Monitoring should continue to ensure these measures are maintained as long as there continues to be a risk from on-site contaminants. Security measures were implemented during TCRA cap construction, including a manned security guard shack, roving security patrol, installation of security cameras, and requirement of visitors to sign in at a security checkpoint (Anchor QEA 2012). The security equipment was demobilized upon completion. Upon commencement of further construction activities, security measures should be reinstated to protect against unauthorized entry.

It is unclear whether water-side perimeter controls are sufficient. Access to the site by boat is currently constrained to the north, west, south, and southeast by industrial use and navigational hazards (Anchor QEA 2014). As stated, warning signs on steel posts are in place to warn passing vessels. During construction, Alternatives 4N and 5aN call for sheet pile barriers, and Alternatives 5N and 6N include the use of a silt curtain as measures to control resuspension. Warnings posted outside of these measures should deter vessel traffic during construction. More robust engineering controls to restrict vessel traffic over the long term could be considered such as the use of caissons, or vessel exclusion barriers. The FS suggested a five-foot high submerged rock berm outside the perimeter of the Permanent Cap to protect from potential vessel traffic for alternatives involving the Permanent Cap (3N, 4N, 5N, 5aN). Shallow areas can be isolated using steel cable or chain with appropriate marine and land-based signage and markers to prevent vessel access. The long-term need for such measures depends on the selected alternative, and the extent to which contamination is left on-site, and the need to protect a cap. The ICs discussed in the FS included the need to establish limitations on dredging and anchoring within the footprint of the Armored Cap (Anchor QEA 2014). This would be needed for all alternatives until such time as resulting concentrations are shown to be acceptable.

According to the FS, propeller wash from tug boat operations associated with the SJRF operations could disturb sediments in the Upland Sand Separation Area, but the existing TCRA cap and proposed Permanent Cap would resist such erosive forces (Anchor QEA 2014). Alternative 6N would not result in a Permanent Cap, but instead would rather be covered with 6 inches of clean cover. If residual concentrations are not sufficiently low, a no-wake zone may need to be established for Alternative 6N, as well as for the Upland Sand Separation Area. Alternatively, an armored cap could be considered for Alternative 6N.

A TxDOT Agreement was put into place during TCRA construction in which TxDOT is required to receive three-day notice before commencement of construction activities, and requires TxDOT to provide notice should any future construction disturb sediments of the San Jacinto River. However, procedures are not currently in place to alert future landowners of the TCRA Site to the potential risks of exposing the capped sediment (Anchor QEA 2014). There are also no current restrictions on dredging or anchoring at the site. As called for in the alternatives including ICs described in the FS, additional measures are needed to alert future property owners of the presence of subsurface materials exceeding PCLs and management requirements for any excavated soils or sediment exceeding PCLs. Enforcement tools such as administrative orders can be used to direct current property owners to perform certain actions such as implementing ICs (including management of excavated soils or sediment). However, most enforcement agreements do not run with the land. Proprietary controls such as covenants may be needed to establish an IC when the property is transferred to another party. Informational devices such as a deed notice could be used to provide information about health risks from contamination left on the site to future property owners. State registries of hazardous waste sites also contain information about contaminated properties. For the nearshore areas or the upland area of the southern impoundment, more traditional ICs may be considered such as land use restrictions against construction, excavation, or other disturbances that may expose contamination. Zoning may be used to restrict land use to industrial purposes or to prohibit groundwater uses. According to the FS, groundwater is not a significant source of dioxins or furans (Anchor QEA 2014), and thus groundwater use restrictions may not be necessary. The intent of Alternative 6N is full removal of all materials exceeding PCLs for protection of the hypothetical recreational visitor, potentially allowing for less restricted future use of the property. If successful, future controls may not be necessary. However, if dredging residuals leave a layer of material exceeding PCLs, ICs will be needed to alert property owners. Easements will need to be in place both during construction and in the future to allow monitoring and maintenance of ECs.

Several of the Alternatives (3N, 4N, 5N, 5aN, 6N) will require staging areas to store clean fill material or armor stone, and areas to dewater and treat excavated cap material and contaminated sediment. The size of the staging areas depends on the alternative and the extent of the removal. Engineering and institutional controls will be needed for the staging areas if contaminated material is to be stored there. Perimeter fencing and warning signs will be needed. Silt fence will be necessary to control surface water runoff, along with coverage of stockpiled contaminated materials. The dust control measures (sprinkling) that were used during construction of the TCRA cap may be necessary to minimize dust generation from land activities and application of Portland cement.

As stated in the FS, ICs would be used to describe the need for protective equipment and training if excavation of subsurface materials exceeding PCLs is required. During the TCRA Cap construction, due to the likelihood of coming in contact with dioxin-contaminated waste, workers in the Exclusion Zone were required to have 40-hour HAZWOPER certification and Level D personal protective equipment. The same procedures would need to be implemented for any of the alternatives (4N, 5N, 5aN, 6N) involving potential exposure of contaminated material.

Task 10

Statement

Identify and document cases, if any, of armoring breaches or confined disposal facility breaches that may have relevance to the San Jacinto site evaluation.

Findings

After an extensive literature review, there appear to be no documented cases of any armored cap or armored confined disposal facility breaches. However, there have been many occurrences of breaches and slope failures of armored dikes, jetties, and breakwaters, with some of those structures confining dredged material. These typically occurred due to ineffective filtering between the armor and core material, insufficient armor sizing for wave action velocities, and steep side slopes allowing rock to be more easily displaced. Table 10-1 briefly describes several cases including a description of the site, the cause of the breach, and if any repairs were made to the structure. The cases shown in Table 10-1 represent varying situations that may be of some relevance to the San Jacinto site investigation because the site is adjacent to a well-traveled waterway with significant wave action due to navigation, is subject to large storm events that may cause large inflows of water from overtopping the CDF, and has armored slopes with synthetic material acting as a filter or liner that is susceptible to tears that allow erosion to degrade the system. None of the listed cases completely breached or failed and were discovered by routine inspections. Repairs and rehabilitation measures, when documented, were easily made.

Table 10-1. Descriptions of Armor Breaches and Failures				
Site Name/ Location	**Site Details**	**Breach/Failure**	**Rehabilitation/Repairs**	**References**
Cox Creek DMCF, MD	Reactivated facility originally built in 1960's. Consists of a containment dike roughly 5000 ft stabilized with concrete vats and slabs.	Original armoring was not sufficient in protecting against erosion from wave energy. Before rehabilitation, side slopes had eroded to 1:1	Rehabilitation from 2002 - 2006 included stabilizing the dike before replacing armor stone.	Kotulak *et al*. (2007)
Chicago CDF, Calumet Harbor, IL	17-ha nearshore CDF with a rubble mound dike constructed of a core of limestone, a synthetic membrane liner along the inside face to prevent excess migration of fine dredged material solids through the dike as it is filled, and armor stone.	The fluctuating levels during and after construction revealed that the liner was ineffective due to tears resulting from punctures during the placement of the armor stone or from the limestone core.	A sand blanket was selected as the appropriate corrective action and placed along the inside face of the dike. Further fine grained material was placed along the inside face of the dike to improve the effectiveness.	Savage (1986), Palermo, *et al.* (2000)
Port Chehalis Revetment, WA	South jetty originally built in 1929, reconstructed between 1935 & 1939 and has been improved over the years by the addition of 6 groins and a revetment wall connecting the groins.	Routinely incurs damage from winter storm wind and waves as well as overtopping resulting in erosion of the core material and the settlement and displacement of the armor.	Major rehabilitation in 1972 reinforced groins A-D, F and added groin E. Emergency repairs were made to groin E and the revetment wall after a winter storm caused significant damage in 1999. In 2010, erosion to the revetment was repaired by the addition of Class V stone and Class I filter stone. In 2013, proactive measures were taken by the addition of stone to the revetment increase the thickness of the structure.	USACE, Seattle District (2013)
Atlantic Harbor of Refuge Breakwater, NC	A 2000 ft. sand breakwater with a riprap head was constructed in 1972.	Significant erosion occurred along the southeastern face of the breakwater leading to a large escarpment of 3 ft and displacing the armor stone protection. The sand fill behind the stone eroded way undermining the rock and displacing it.	As of 1985, no rehabilitation or repairs have been made.	Sargent, USACE (1988)

Site Name/ Location	Site Details	Breach/Failure	Rehabilitation/Repairs	References
Two Mile Breakwater, Two Mile Florida	The two breakwaters were constructed in 1976 on either side of the entrance to Two Mile Channel and were designed to retain dredged material. The L-shaped dikes were built up using bottom material and were revetted with filter fabric and rubble stone.	The outer ends began eroding significantly by 1982.	Additional rubble stone was added to the ends of the breakwaters to protect against erosion.	Sargent, USACE (1988)
Siuslaw River Jetties, OR	Two entrance jetties to the Siuslaw River have been improved and altered since their original construction in 1917. The jetties were extended seaward in 1985 and spurs were added to the ocean side of each jetty. The jetty expansion and spurs were constructed of randomly placed rubble and armored with 12-19 ton stones.	Wave actions eroded the heads of each jetty where slopes were steep and armor stones were pulled down by wave action. Erosion also occurred along the jetty spurs and voids in the jetty were found.	No repairs detailed in survey; however, it is recommended that armor stones be placed in the voids and damaged areas to prevent further damage during a major storm event.	Bottin *et al.,* USACE (1999)
Yaquina Bay North Jetty, OR	Located in the Yaquina Bay on the Oregon coast, two parallel rubble mound breakwaters with the final extension of the south jetty being completed in 1972 and experiencing no major problems. The final extension of the north jetty was completed in 1966.	The north jetty routinely experiences severe wave conditions that damage the jetty. The seaward side is primarily affected with stone being removed and the jetty eroded.	The north jetty has been rehabilitated twice since the completion of the extension. In both instances, the repairs were made to the seaward side where rock had been removed below the water level. Survey recommends additional armor stones be placed to prevent future damage.	Bottin *et al.*, USACE (1999)

Site Name/ Location	Site Details	Breach/Failure	Rehabilitation/Repairs	References
Burns Harbor Breakwater, IN	The Burns Harbor located on the southern shore of Lake Michigan, includes two rubble mound breakwaters. The breakwaters were constructed with a multilayered design and random placement of armor stones consisting of rectangular-cut Indiana- Bedford limestone blocks.	Since completion of construction, extensive damage has occurred including the displacement of much of the armor stone. Inspections also noted that erosion had created large voids under the rock and that the breakwater was deteriorating. Navigation induced and wind and wave actions are the primary cause of damage to the breakwater.	In the first 19 years of operation alone, an average of 7,640 tons per year of stone were placed on the breakwater with both the lakeside and the harbor-side receiving equal distributions of stone. Construction of a submerged, offshore reef breakwater was designed to reduce wave heights along the north breakwater and decrease waves in the harbor.	Bottin *et al.*, USACE (1999)
Cattaraugus Creek Harbor, NY	Cattaraugus Creek Harbor is located on Lake Erie and consists of two breakwaters at the mouth of the creek. Both are rubble mount structures with a concrete cap on the south structure. The original armoring ranges in size from 2 - 13 tons.	Monitoring took place after construction and it was noted that damage occurred on the south breakwater primarily due to stone cracking. The loss of shattered stone resulted in adjacent stones collapsing into voids creating a steeper slope on the structure. The lakeside of the breakwater receives the bulk of the wave action and therefore carries the majority of the damage.	No repairs detailed in survey; however, it is recommended that armor stones be placed in the voids and damaged areas to prevent future damage.	Bottin *et al.*, USACE (1999)
Ocean City Inlet South Jetty, MD	The Ocean City Inlet consists of two jetties and three headland breakwaters to stabilize the pass. The south jetty was originally constructed in 1935 and an additional section was added in 1985. The new section was constructed with core stone, intermediate stone, capstone and precast concrete units to minimize sand transport.	While the added section of the south jetty has performed and help up well, the original portion of the south jetty has considerably deteriorated. The armoring stones had scattered and due to erosion, the crest of the jetty had been reduced unevenly.	No repairs detailed in survey.	Bottin *et al.*, USACE (1999)

Task 11

Statement

Assess the potential amount or range of sediment resuspension and residuals under the various remedial alternatives including capping, solidification, and removal.

Findings

It is standard

Task 12

Statement

Identify and evaluate techniques, approaches, Best Management Practices (BMPs), temporary barriers, operational controls, and/or engineering controls (*i.e.*, silt curtains, sheet piles, berms, earth cofferdams, etc.) to minimize the amount of sediment resuspension and sediment residuals concentrations during and after dredging/removal. Prepare a new full removal alternative that incorporates the relevant techniques identified as appropriate.

BMPs to minimize Sediment Resuspension and Residuals during Dredging/Removal

Alternatives 4N, 5N, 5aN and 6N call for removal of a portion of the TCRA cap composed of armor stone and filter stone in the Northwestern Area, armor stone and geotextile in the Eastern Cell and armor material, geotextile and geomembrane in the Western Cell. Alternatives 5N, 5aN and 6N also call for partial or full removal of sediment. These removal operations will resuspend contaminated sediment and generate contaminated residuals which will increase the release of contaminants, requiring the implementation of Best Management Practices (BMPs) to control the release of contaminants.

Resuspension, Residuals, and Release

Sediment remediation techniques that disturb the sediment bed, such dredging, solidification, or treatment, have potential to expose contamination through resuspension, generation of residuals, or release of contaminants. Detailed information regarding these mechanisms with respect to dredging is provided by ERDC in the Technical Guidelines for Environmental Dredging of Contaminated Sediments (Palermo *et al.* 2008). Resuspension is the dislodgement and dispersal of sediment into the water column where finer particles and flocs are subject to transport by currents. Resuspension results in short-term release of contaminants by desorption and release of pore water. Residuals are contaminated sediments remaining in the dredging area after completion of the dredging operation and result from two main sources. Undisturbed residuals are contaminated sediments at the post-dredge surface that have been uncovered, but not removed. Generated residuals consist of sediment that

is dislodged, but not removed, and falls back into the dredging footprint where it contributes to contaminant release (Palermo *et al*. 2008).
A variety of control measures have been identified to minimize sediment resuspension, contaminant release and dredging residuals that may occur during sediment removal operations. These include both operational and engineered controls. Operational controls include actions that can be taken by the dredge operator, whereas engineered controls require a physical construction technology or modification of the dredge plant. It is pointed out in the Technical Guidelines (Palermo *et al*. 2008) that both, operational and engineered controls can reduce production rates and efficiency, can increase cost, and can even have negative impacts if used improperly, and therefore should only be applied when conditions clearly indicate their need.

Resuspension Controls

<u>Operational Controls</u>

Operational controls that may be considered to minimize resuspension during dredging include:

Mechanical Dredging:

- Reducing the dredging rate by slowing descent or hoist speed of wire-supported bucket
- Reducing bucket speed as it approaches sediment surface and after closing
- Prevent bucket over-penetration
- Eliminate barge overflow
- Employ aprons to catch spillage and a rinse tank to clean the bucket between cycles

Hydraulic Dredging:

- Modify cutterhead depth
- Modify rate of swing of the ladder
- Reduce speed of advance of the dredge

General:

- Adjust dredge operation according to changing site conditions
- Sequence the dredging moving upstream to down and to limit dredge traffic over exposed contaminated sediment
- Vary number of vertical cuts to increase sediment capture
- Use properly sized tugs and support equipment

- Limit barge, tender and tug traffic over exposed sediment and residuals
- Cover exposed residuals as soon as possible, minimizing the area of exposed residuals

Dredge operators are challenged to find an optimal rate to reduce resuspension and maximize production. For hydraulic dredging, resuspension is generally minimized at the same point that production is optimized.

<u>Engineering Controls</u>

Engineered control measures such as physical barriers can be used to reduce transport of resuspended contaminated sediment, and limit the areal extent of particle-bound contamination. However, containment of the resuspended sediment may increase residual concentrations inside the barrier. Types of physical barriers may include cofferdams, removable dams (*e.g*. Geotubes), sheet-pile enclosures, silt curtains, silt screens, and pneumatic (bubble) curtains. Cofferdams and removable dams are generally associated with dry excavation remedies.

Silt curtains and silt screens. Silt curtains and silt screens are flexible barriers that hang down from the water surface using a series of floats on the surface and a ballast chain or anchors along the bottom. Silt "curtains" are made of low permeability materials, and as such, redirect water flow around the enclosed area. Silt "screens" are made of permeable geotextile fabrics which allow a significant fraction of the water to flow through, but retain a large fraction of the suspended solids. The terms are frequently used interchangeably, and the term "curtain" is used here to apply to both types. Silt curtains either contain or redirect the transport of resuspended sediment. Partial depth deployment from the surface to a given depth prevents spreading in the upper water column, but allows transport beneath the curtain. Full depth deployment provides greater containment, although there are potential releases from ineffective seals along the bottom, tidal fluctuations, erosion by the curtain scraping the sediment bed, erosion outside the curtain from the flow being diverted around the site, and vessel movement through gaps. It is important to note that increased concentrations of TSS or dissolved contaminants contained within the curtain are generally released upon relocation or demobilization.

Guidance on the use of silt curtains, including descriptions, deployment, configurations, and "lessons learned" is provided by Francingues and Palermo (2005). Some of the key points include:

- Silt curtains are not very effective at current velocities >1 ½ knots (2.5 ft/sec) and are best deployed in environments where the current speeds are less than 1 ft/sec. Application at higher velocities would require special designs.
- At depths greater than 10-12 ft, loads on the curtains and mooring systems become excessive and could result in failure.
- Silt curtains are highly specialized and should be tailored to the site-specific project. Planning elements should include construction specifications, performance criteria, plans for deployment, removal, decontamination and maintenance, and monitoring plans.
- Deployment is temporary, but should remain in place until all dredging is complete, allowing for traffic in and out, and for relocation as the dredge moves.

Hydrodynamic conditions that reduce effectiveness of the silt curtain include strong currents, high winds, fluctuating water levels, excessive wave height (including ship wakes), drifting ice and debris, and movement of equipment into or out of the area. Generally, silt curtains are most effective in relatively shallow, quiescent water without significant tidal fluctuations. Silt curtains can be used either to enclose the dredging area (keeping TSS inside), or to protect sensitive areas (keeping TSS out).

Structural barriers. Structural barriers should be considered if there is uncertainty that a silt curtain will be effective, or for containment of resuspended sediments that contain highly mobile, highly toxic, or bioaccumulative contaminants. Structural walls (*e.g.*, sheet pile deflection walls) can also be used to partially shield silt curtains from high current velocities. Sheet-pile containment structures are generally more reliable than silt curtains, although the cost is significantly higher with different technological limitations. There is an increased potential for scour to occur around the outside of the containment area. Another consideration is the resuspension and contaminant release that will occur during placement and removal. If water levels are lowered on one side of the wall, the hydraulic loading effects may result in safety concerns; however, the wall can be designed to allow water exchange to accommodate changes is river stages or tides. If the carrying capacity of a stream or river is changed significantly, it may make it more susceptible to flooding. Engineering design considerations include geotechnical characteristics of the sediment profile, proximity to bedrock, hydraulic head acting on the enclosure, and ice forces.

Release Controls

Controlling resuspension is the first step to controlling release of contaminants because the vast majority of dioxins and furans are associated with the sediment particles. However, additional controls may be necessary because the contaminants will partition to the water column when sediment particles are suspended in dispersions of low concentrations of total suspended solids.

For release of NAPL and floatable materials, oil booms may be used to contain contaminants. Oil booms may be supplemented with oil-absorbent materials. However, booms do not retain the soluble fraction of floatable materials that can volatilize. Monitoring for visible sheens or visibly soaked sorbent pads and changing out pads accordingly can improve effectiveness. NAPL and floatable materials are not a concern at the San Jacinto site.

Controlling release of particulate-bound contaminants is largely accomplished by controlling resuspension. However, increasing sedimentation rates will also decrease the spread of contaminants and bioavailability. Methods to improve sedimentation include: providing a zone for quiescent settling, addition of flocculants, or using containment enclosures designed as filters. Adsorbents integrated into permeable silt curtains essentially treat water as it passes through. Pilot studies may be needed to show effectiveness of these technologies.

Technology for controlling releases of dissolved contaminants is also largely limited to resuspension controls. However, dissolved contaminants may also be removed by dispersing adsorbents, such as activated carbon, inside containment enclosures. Upon settling, the adsorbents may further sequester the dissolved contaminant flux from the sediment bed and residuals. If the sediment bed or residuals were resuspended, the adsorbents would also be resuspended and then sequester the new releases. Filtering geotextiles with adsorbents used in conjunction with permeable silt curtains treat water passing through the site. Pilot studies are encouraged before application to large-scale projects.

Volatile emissions controls are limited and have not been adequately evaluated in the field. In addition to the controls mentioned above, controls for small hotspots may include: modifying the dredging schedule or sequence to dredge in winter or at night when temperatures are cooler; using hydraulic dredging to reduce concentrations at the water surface and in the air; applying surface volatilization barriers; and reducing the area of the dredge enclosure that is emitting volatiles. Other physical measures to control volatiles include covering the dredged material with physical barriers (*e.g.*, foam, mulch, plastic liner, or adsorbent mats). Dioxins and furans have both low solubility and low volatility; therefore, volatilization controls are not needed at the San Jacinto site.

Residual Controls

The nature and extent of residual contamination is difficult to estimate. Undisturbed residuals can be reduced by accurate and precise site characterization, proper establishment of the cut line, accurate and precise vertical and horizontal controls for positioning of dredge passes, accurate post-dredging bathymetric surveys, and an accurate cleanup pass. Generated residuals, however, are unavoidable, and it is accepted that a residuals layer will be present unless eroded away. The operational controls listed below may be effective for reducing residuals.

- If debris is present, a separate debris-removal operation can be considered either prior to dredging, in between passes, or prior to a cleanup pass. Little debris should be present in the contaminated sediment due to nature of the San Jacinto waste pits being a confined waste storage facility, its remoteness, and its lack of commercial or navigation activities at the site.
- Sequence dredging from upslope to downslope and upcurrent to downcurrent and to limit dredge traffic over exposed contaminated sediment.
- Limit traffic over the dredged area.
- Excavate in the dry where possible.
- Provide appropriate overdredging allowance for production cuts.
- Overdredge with a cleanup pass to reduce the residuals layer thickness and mix residuals from the underlying clean sediment with the contaminated residuals to reduce the concentration.

- Provide adequate overlap between bucket cuts with high resolution positioning controls to avoid missed sediments between bucket cuts.
- Terrace dredge cuts to limit sloughing.
- Eliminate bucket over-penetration and overfilling.
- Conduct rapid hydrographic surveys and sampling after dredging to provide feedback to the dredge operator.

Depending on the results of monitoring, several post-dredging control measures are available. The controls measures should be selected based on residuals' characteristics and site conditions.

A cleanup dredging pass or sweep pass may be conducted to remove the thin surficial layer of material containing residuals and minimal thickness of the underlying clean material. Performance requirements to achieve a very low residual contaminant concentration can be inefficient and costly. Limiting the number of passes and providing the option for placement of a residuals cap may bring more certainty into the cost estimating and bidding process. For thicker layers of residuals, especially undisturbed residuals, additional production dredging may be needed.

A thin layer of clean material may be placed over residuals to provide short-term isolation and long-term reduction in surficial contamination. The cover material does not need to be sand, and other materials with potential to reduce bioavailability may be preferable. Thin layer capping may be useful where residual layers are sufficiently thin with low contaminant concentrations, so that if the cover material mixes into the underlying residual, remediation action levels can still be achieved. Some mixing is likely to occur during placement, with additional mixing due to bioturbation and sediment transport processes. This would result in a lower contaminant concentration in the biologically active zone. Additional deposition of clean sediment may enhance physical and chemical isolation of the residuals.

An engineered isolation cap may be considered where substantial layers of residuals cannot be effectively removed. USEPA guidance for design of engineered caps is generally followed (USEPA 2005).

Best Management Practices for San Jacinto Proposed Alternatives

Alternatives currently being considered for San Jacinto are described in the Draft Final Interim Feasibility Study Report (Anchor QEA 2014). Within the management alternatives, a number of actions have been identified that have potential to generate resuspension, residuals, and contaminant release. The alternatives labeled as 1N (no further action) and 2N (monitored natural recovery (MNR) and institutional controls (ICs)) will leave the existing TCRA Armor Cap in place and does not include activities that would generate resuspension, residuals or release. Implementation of Alternative 3N would require enhancement of the Armored Cap including addition of armor rock to further flatten the slopes, and construction of a protective perimeter barrier to protect from vessel traffic. These activities would not expose the contaminated material and therefore would not have the potential to generate resuspension, residuals, and contaminant release. Alternative 4N calls for removal of 23% of the Armored Cap, and solidification/stabilization (S/S) of the underlying 52,000 cubic yards (cy) of contaminated material, followed by construction of a Permanent Cap. Alternative 5N also calls for partial removal of the Armored Cap and Permanent Cap construction, but also specifies excavation and off-site disposal of the 52,000 cy of contaminated material that exceed 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth. More extensively, Alternative 5aN requires removal of the Armored Cap and all underlying material in high concentration areas (>220 *ng/kg* $TEQ_{DF,M}$) with water depth of 10-feet or less, and materials that exceed 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth. Removal for Alternative 5aN would involve 11.3 acres and 137,600 cy of contaminated material. Alternative 6N requires removal of the entire existing cap and 200,100 cy of contaminated material followed by covering with a layer of clean fill.

Activities that may generate resuspension, residuals, and contaminant release include:

- Removal of existing TCRA Armor Cap (under both submerged and upland conditions)(4N, 5N, 5aN, 6N)
- Resuspension and release from exposed, un-capped sediment (4N, 5N, 5aN, 6N)
- Solidification/Stabilization (4N)
- Sheet pile installation and removal (4N, 5aN, maybe 5N)
- Perimeter berm installation and removal (5aN)

- Removal of contaminated soil/sediment (5N, 5aN, 6N)
- Construction of Permanent Cap (4N, 5N, 5aN)
- Restoration of Armor Cap (in areas cap was removed to allow S/S (4N) or removal (5N) of material with TEQ > 13,000 *ng/kg* $TEQ_{DF,M}$)
- Addition of residuals cover/backfill (5N, 5aN, 6N)
- Installation/removal of silt curtain (5N, 6N)
- Site dewatering (4N, maybe 5N, possibly 5aN and 6N in Western Cell)
- Treatment/dewatering excavated sediment (5N, 5aN, 6N)

With dioxins as the primary COC, concerns are primarily associated with particulate-bound contaminants, rather than volatile emissions or dissolved contaminants.

<u>Removal of Existing Armor Cap</u>

Alternatives 4N, 5N, 5aN, and 6N involve removal of some or all of the existing TCRA Armor Cap. Armor cap would be removed from both submerged areas and areas that are not normally submerged though periodically flooded. The armor rock would be removed and stockpiled for reuse, if possible, or washed to remove adhering sediment and disposed in an upland facility. The geotextile and geomembrane would be removed and disposed as contaminated debris (Anchor QEA 2014). Removal equipment and methods were not specified. Alternatives 4N, 5aN, and potentially 5N include sheet pile enclosures, and Alternatives 5N and 6N suggest the use of silt curtain. However, the FS does not clearly specify whether the sheet pile or silt curtain would be installed before or after removal of the existing Armor Cap (Anchor QEA 2014). Dewatering is specified for submerged areas for Alternatives 4N and potentially 5N.

Resuspension is likely to occur as the sediment is disturbed upon removal of cap materials in contact with the contaminated sediment. A significant portion of the contaminated sediment may adhere to the armor rock, geotextile or geomembrane. In submerged areas, contaminated sediment that is resuspended into the water column has the potential for transport off site or for contamination of the clean cap. As part of the TCRA, solidification/stabilization (S/S) techniques were applied to the upper three feet in the Western Cell of the site prior to placement of the Armor Cap. The S/S efforts may have reduced the tendency of the contaminated sediments to adhere to the cap materials and to resuspend. In upland areas such as the Western Cell, contaminants could be transported off site via runoff or as dust.

Some contaminated material will adhere to the cap material (geotextile or armor rock) and be disposed with it. As discussed in the FS, hazardous materials (sediments, geotextile, used personal protective equipment and debris) would be packaged in accordance with Texas Department of Transportation shipping requirements and transported to a permitted landfill. Care should be taken to avoid re-use of cap material that has been contaminated with the sediment. It is difficult to understand how the armor cap material could be readily removed without snagging and disturbing the geotextile and sediment, particularly if performed underwater. The entire cap within the sheet pile enclosure should be removed prior to solidification, excavation or dredging to limit contamination of the TCRA armor cap material. The enclosed area could be sectioned with silt curtains to further limit the potential for contamination of the TCRA armor cap material. Additionally, a work plan should be in place to minimize equipment tracking between capped (or clean) and exposed contaminated areas. Periodic equipment cleaning could be employed to prevent contamination of otherwise clean, reusable cap materials.

In submerged areas, installation of sheet pile walls prior to cap removal would provide a barrier to contain resuspension from cap removal activities and reduce off site transport. If dewatering is possible, working in the dry would significantly reduce contaminant transport from resuspension and release. Though not as effective as sheet pile, silt curtains could also be used to reduce transport of resuspended contaminated sediments. Problems with silt curtains were noted during the TCRA cap construction, yet despite requiring a great deal of maintenance, the silt curtains appeared to be effective (Anchor QEA 2012). Resuspended sediment contained within the sheet pile or silt curtain enclosure may subsequently settle out within the contained area, which could contaminate remaining un-removed cap material. (See Sheet Pile and Silt Curtain Installation/Removal.)

Resuspension and Release from Exposed Un-capped Sediments

Removal of the existing cap (Alternatives 4N, 5N, 5aN) will also expose the contaminated sediments for a period of time until they are either stabilized, removed, or either covered or capped. There is potential for contaminants to be released into overlying water during exposure. Exposed upland soils can also be transported by rainfall runoff and dust. Also, resuspension of the contaminated material is possible during storm and flood events, which could allow transport to the surrounding area. The risk of flood occurrence depends on the season and duration of the construction. For alternatives 4N and 5aN, the area in which the cap will be removed will be enclosed within sheet pile. However, the FS suggests the likelihood of the sheet pile being overtopped and resulting in inundation of the construction footprint is approximately 38 percent for alternative 4N, and 40 percent for alternative 5aN. Alternatives 5N and 6N, using silt curtains, are also subject to inundation, with a likelihood of 30 percent and 36 percent, respectively (Anchor QEA 2014).

Potential practices that could minimize contaminant resuspension and release from exposed sediment include the use of silt curtains, or sheet piles. The FS report suggests limited effectiveness of the sheet pile due to gaps during construction, necessary openings to balance water pressures, and river-induced scour (Anchor QEA 2014). However, use of sheet piles in shallow water such as along the berms of the Western Cell may be able to operate in the dry. In deeper areas the remediation operations would need to proceed in the wet, use of sheet piles for controlling resuspension losses and contaminant releases would be much more effective than silt curtains even if water exchanges were allowed to balance water pressures. Exchanges would occur near the surface with sheet piles but near the bottom for silt curtains, resulting in about one third of the releases observed using silt curtains. Additionally, armoring around the outside of the sheet pile wall could control river-induced scour. For resuspended sediment that is contained within a sheet pile (4N, 5aN) or a turbidity curtain (5N, 6N), flocculants may be added to encourage settling of contaminated particles. Also, activated carbon may be added to sorb dissolved contaminants. As both silt curtains and sheet piles may leak, additional practices may be needed to manage contaminants released outside the contained area. Monitoring is recommended to determine the need for such controls.

For upland areas, water spraying should be employed as needed to control dust. Also, exposed sediment is subject to resuspension during rainfall runoff or tidal inundation. Silt fencing or hay bales may be used to minimize release of contaminated sediment-laden runoff. Also, during TCRA Armor Cap construction, a temporary water control berm was constructed to minimize potential for tidal water to inundate the Western Cell during stabilization activities. The berm was constructed with a crest elevation of approximately 2.5 feet NAVD 88, using CCRB and 6 mm thick polyethylene sheeting (Anchor QEA 2012, p. 39). Potentially, the surface area exposed at a given time could be reduced by staging the construction activities, working within subareas, and using sacrificial covers which would support fill, bedding or filter requirements for the final disposition.

<u>Solidification/Stabilization</u>

Alternative 4N proposes S/S performed using large-diameter augers or conventional excavators, similar to those used for S/S in the Western Cell during the TCRA. Submerged areas would be isolated from surface water with sheet pile and mostly dewatered prior to S/S. The FS assumes a sheet pile enclosure with a top elevation 2 feet above typical mean higher high water (mhhw). The sheet pile would be removed following completion of S/S; then, the Permanent Cap would be constructed over the S/S footprint. None of the other alternatives include S/S activities (Anchor QEA 2014). S/S activities will potentially result in resuspension, release, and residuals as the uncapped contaminated material is mixed with Portland cement. Mixing of the sediment will loosen it, making it temporarily more subject to resuspension and erosion. However, the S/S treatment will increase resistance to erosion as it cures over a period of about ten days. In upland areas, runoff controls should be in place to capture suspended sediment from rainfall. The FS suggests that the submerged areas be enclosed with sheet piles and dewatered. If not dewatered, sheet pile enclosures would also help retain resuspended solids, and released contaminants. The FS suggests ineffectiveness of sheet pile barriers due to gaps that occur during installation, openings to balance water pressures, and river-current-induced scour. If properly installed, shallow sheet pile barriers should be able for the most part to be installed without gaps, and any gaps could be sealed with fine-grained backfill. If water pressures are significant, a cofferdam may be needed. If S/S is performed in the wet, the degree to which resuspension occurs will depend on the equipment used to mix the sediment and cement.

S/S activities will involve transport across the site to maneuver mixing equipment and deliver Portland cement. To minimize contaminant spreading, decontamination of trucks and equipment (and workers) may be needed upon exiting the site. A water truck may be needed to suppress dust from both the contaminated sediment and Portland cement.
Post S/S monitoring will be needed to determine the extent to which S/S is effective for stabilizing contaminants. Residual contamination is addressed by the planned Permanent Cap, MNR, and ICs. Residuals may be further managed by addition of activated carbon prior to capping.

Sheet Pile Installation and Removal

For Alternatives 4N, 5aN, and potentially 5N and 6N, a sheet pile wall has been suggested as a means to dewater submerged areas and/or manage resuspended contaminated sediment. However, there are also risks associated with both installation and removal of the sheet pile itself. The FS suggests that sheet pile would be driven through the existing TCRA Cap. Although this approach allows coverage of the contaminated sediments during construction, it is not recommended because of the difficulties associated with driving sheet pile through the large armor rock, and achieving a tight seal between joints. Instead, it is recommended that a portion of the rock armor be removed from the sheet pile footprint, and the geotextile or geomembrane cut and peeled back to avoid damage or shifting during sheet pile installation. Activities associated with driving the sheet pile will disturb the exposed sediment causing some limited resuspension, considering that the sediment has been consolidated under the armor cap and geotextile. Additionally, the impact should be relatively small due to the small footprint required for the sheet pile.

Additional resuspension and release is likely to occur during removal of the sheet pile allowing recontamination of the cap or release of contaminants off site. The sheet pile will likely be driven through the entire depth of the contaminated sediment to achieve stability. Upon removal, sediment that adheres to the sheet pile will be subject to resuspension in the water column. Sheet pile should be removed carefully to minimize resuspension. The cap in the area from which the sheet pile was removed will need to be restored.

During the course of construction activities suspended sediments will accumulate within the enclosed area; however, considering the brackish nature of the site water flocculation and settling will maintain relatively low concentrations of total suspended solids, probably a concentration of less than 250 *mg/L*, within the enclosure. Upon removal of the sheet pile, this sediment laden water may be released allowing transport of contaminants offsite. At a minimum, it is suggested to allow time for particulates to settle after construction activities cease prior to sheet pile removal, the vast majority of the suspended solids should settle within a day. Flocculants may also be used to promote settling and create dense, strong flocs that would settle in minutes. Furthermore, dispersal of activated carbon may be used to adsorb dissolved contaminants. Once deposited on the bottom, the carbon would continue to treat contaminants on the surface.

<u>Silt Curtain Installation and Removal</u>

The FS recommends a silt curtain be installed for Alternatives 5N and 6N. Installation of silt curtain should not cause significant resuspension of contaminated sediment. As with sheet pile, suspended contaminated sediment and dissolved contaminants that builds up behind the silt curtain is subject to release during curtain removal; however, this quantity would be expected to be quite small considering the exchange of water that will occur at the site. Silt curtains do very little to control losses at the bottom of the water column. Consequently, use of flocculants to promote settling and/or activated carbon to adsorb dissolved contaminants would not provide much benefit immediately prior to silt curtain removal. Silt curtains should be removed by pulling both the top and bottom lines, or by furling the curtain and removing with a boat.

As noted in the TCRA Final Removal Action Completion Report (Anchor QEA 2012), issues were experienced with the use of a turbidity curtain during the TCRA implementation. The turbidity curtain was subject to river currents and tidal fluctuations, and frequently shifted position. Repositioning and management of the curtain was needed on a regular basis. The strain resulted in detachment from the anchors, and tearing of the floating boom from the submerged skirt. It was noted that in some situations, the curtains can cause more resuspension than if the curtain were not there. Despite the problems, the silt curtain was considered effective. Sheet pile barriers such as proposed for Alternatives 4N and 5aN should also be considered.

The location of the proposed silt curtains was not specified. Some distance should be maintained between the silt curtain and the work area to allow for shifting of the curtain due to tidal fluctuation. Silt curtains may also increase turbidity and scour along the bottom due to movement along the bottom as well as increased current velocities underneath the curtain; however, this would not be a concern if the silt curtain were placed over the TCRA cap.

Site Dewatering

Site dewatering is suggested in the FS for Alternatives 4N, maybe 5N, and possibly in the Western Cell for 5aN and 6N. Site dewatering in submerged areas would require isolation with sheet pile (which has been addressed), berms, cofferdam, or removable dams (geotubes). Upland excavation that occurs below the groundwater table may also require dewatering. Dewatering effluent would need to be treated or shipped to a licensed facility.

Perimeter Berm Installation and Removal

To manage water quality during construction, Alternative 5aN includes an earthen berm in shallow water (depths up to approximately 3 feet), extending to an elevation at least 2 feet above mhhw, but limited to a total height of 4 to 5 feet above the existing mudline. In greater water depths, the berm would transition into a sheet pile barrier. It is assumed that the existing TCRA cap would be removed from the berm area prior to berm construction, thus exposing the geotextile or underlying contaminated soils/sediments. Conventional earth-moving equipment would likely be used to construct the berm. Berm construction activities could disturb the underlying sediments, resulting in resuspension. It appears sediments in the berm vicinity have concentrations < 220 *ng/kg* TEQ, yielding limited potential for significant loss of contaminant mass.

Presumably, the containment berm will be removed after excavation and backfilling has been completed within the enclosed area. Care should be taken during removal minimized disturbance of the backfilled area. Alternatively, the berm could be left in place to protect the site from barge strikes under high water conditions.

Removal of Contaminated Soil/Sediment/Sludge

Alternatives 5N, 5aN and 6N involve removal of varying amounts of contaminated sediment. Alternative 5N would remove soil and sediment with concentrations exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ (52,000 cy). Alternative 5aN would remove soil and sediment exceeding 220 *ng/kg* $TEQ_{DF,M}$ where the water depth is 10 feet or less, and soils exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ at any depth (137,600 cy total). For Alternative 6N, all soil/sediment exceeding 220 *ng/kg* would be removed (200,100 cy). Water-side removal may occur via dredging, although the dredge type is not specified in the FS. The FS also refers to the possibility of dewatering the work area and using land-based earth-moving equipment, particularly in the Western Cell and perhaps shallow portions of the Eastern Cell. Upland excavation would be accomplished with conventional earthwork equipment (excavators, dozers, loaders, etc.). For upland excavation below the groundwater table, ditches, sumps, wellpoint systems or deep wells are discussed in the FS for water management. Dewatering effluent may need to be treated or shipped to a licensed facility (See Site Dewatering).

Land-based removal will involve disturbance of contaminated sediments with earthwork equipment. Risks include equipment tracking contamination off site, transport of disturbed sediment via dust or rainfall runoff, as well as residual contamination that is left in place. Water spraying may need to be employed to control dust, and silt fence or hay bales to prevent transport of runoff particulates. A work plan is needed to sequence excavation in order to minimize cross contamination of clean areas. Periodic equipment cleaning, such as prior to leaving the site may also be used to avoid spreading contamination.

Upon excavation, the material would likely be transported to an area where it is stockpiled prior to dewatering. Areas used to stockpile contaminated materials should also be managed to control dust and runoff, such as covering stockpiled materials, and the use of silt fence barriers. There are also risks associated with spills during transport to the disposal facility and releases from the landfill itself, which are not addressed here. Depending on the results of monitoring, a cleanup pass may be used to remove the top layer of soil with residual contamination.

For dredging activities, management strategies are needed to control resuspension, contaminant release, and residual contamination. Engineered barrier controls (sheet pile and earthen berm for Alternative

5aN, turbidity curtain for Alternatives 5N and 6N) are included in the FS, and would be appropriate for containment of resuspension. Although, the FS assumes a certain degree of leakage of these barriers, careful installment and management will optimize their efficiency.

Controls are needed for contaminated residuals that are left in place. For Alternatives 5N, 5aN and 6N, the FS calls for covering the excavated areas with backfill. Alternative 5N would be further covered with a permanent rock armor cap. Therefore, the dredge cut should be designed to leave a slope no greater than 1V:5H to permit placement of a stable cap or backfill. Monitoring post-dredging should be done to determine the need for controls to manage residuals left in place. A cleanup dredging pass may be useful to remove some of the residuals. A layer of carbon placed prior to backfilling, or blended with the backfill material would protect against contaminant releases from residuals (in both upland and submerged areas). Activated carbon has been shown to sequester dioxins and furans and reduce bioavailability (Chai *et al.* 2012, USEPA 2013). Carbon (or other amendments) may be delivered using engineered amendments such as AquaGate+™, which may both increase cohesion to prevent erosion, as well as adsorb contaminants. MNR is also planned, as natural deposition is predicted to occur. Institutional controls are also planned for long-term management of contaminants left on site.

<u>Permanent Cap Construction</u>

Alternatives 3N, 4N, 5N and 5aN include different variations of construction of a Permanent Cap. Each of the alternatives includes addition of armor rock and rubble mound protection to the existing Armor Cap to flatten the slopes and improve stability. A protective perimeter barrier consisting of a submerged rock berm would also be constructed to protect the cap from vessel traffic. Alternatives 3N and 5aN involve placement of armor rock over top of the existing cap and construction of the rock berm.

For Alternative 3N, there is little risk associated with resuspension of contaminated sediments during Permanent Cap construction, as the existing TCRA cap will be in place and intact. With Alternative 5aN, in the area adjacent to that planned for Permanent Cap construction, the existing cap will have been removed, and contaminated sediment excavated (> 220 *ng/kg* TEQ), and backfilled with 6 inches clean sediment. Assuming the

Permanent Cap will be constructed after placement of backfill, care should be taken to avoid disturbing the backfill. It is unclear whether the Permanent Cap area will be inside or outside the sheet pile and berm enclosure used to control resuspension during excavation, but presumably it would be constructed with the sheet pile wall and berm in place to control potential losses during cap placement.

In addition to the rock berm and placement of rock over the existing cap, Alternatives 4N and 5N also include construction of the permanent cap over areas of contaminated sediment where the existing TCRA cap was removed. Replacing cap that was removed is referred to as armored cap restoration and discussed below.

<u>Restoration of Armor Cap</u>

For Alternatives 4N and 5N the existing TCRA cap will be removed in areas to allow S/S (4N) or removal (5N) of material with TEQ > 13,000 *ng/kg*. After S/S or excavation, the Armored Cap will be replaced, which will include replacement of the armor rock layer, geomembrane and geotextile. Geomembrane or geotextile and armor rock should be placed carefully to minimize resuspension. It was noted in the TCRA Final Removal Action Completion Report (Anchor QEA 2012), that site monitoring of turbidity resulting from tugboat and barge movement around the TCRA Site during water-side placement activities showed no exceedances that would trigger additional BMPs. However, resuspension could be greater for Alternative 5N due to the presence of residuals and the loss of sediment strength from recent disturbance induced by the removal operation.

Plans for Alternative 4N include a sheet pile wall which will retain resuspended material. Presumably the sheet pile will remain in place until after the armor cap is restored. Alternative 5N may incorporate use of silt curtain rather than sheet pile walls for containment, which will provide some retention of resuspended solids. For Alternative 4N, the replacement will occur on top of stabilized soil/sediment which should improve cohesion and reduce resuspension. The Western Cell area is primarily upland, whereas the area in the Eastern Cell is submerged, although sheet pile containment is planned, with possible dewatering. Assuming the site is not dewatered, concentrations of resuspended contaminated sediment may have built up during S/S activities. Settlement of the resuspended solids should be allowed (either waiting a period of time, or enhancing settling by flocculant addition) prior to cap placement to avoid contaminating the clean cap. The cap placement should be sequenced so as to minimize equipment contact with the contaminated soils/sediments.

Addition of Residuals Cover/Backfill

Alternatives 5N, 5aN, and 6N would include backfilling the areas that are excavated with 6-inch thick cover. The backfilled areas in Alternative 5N would subsequently be covered with an armored cap. Natural deposition is further expected to cover the site; however, deposition rates are low in most areas, particularly shallow areas. For Alternative 5N, soils/sediments exceeding 13,000 *ng/kg* $TEQ_{DF,M}$ would be removed prior to backfilling. For Alternatives 5aN and 6N, the soils/sediment exceeding 220 *ng/kg* $TEQ_{DF,M}$ would be removed, thus backfilling would occur over top relatively clean soil/sediment, with the exception of residuals. Backfill should be place in such a manner as to minimize disturbance of the residuals and underlying material. This includes sequencing the activity such as to minimize equipment tracking between backfilled and exposed areas.

Treatment/Dewatering Excavated Sediment

Landfills have been tentatively identified for disposal of materials from the site. Sediment dewatering by amendment prior to transporting for disposal is suggested for Alternatives 5N, 5aN and 6N in order to reduce potential mobility of contaminants during transportation and at the disposal facility. An off-site facility with water access has been suggested for processing dredged sediment prior to shipment. The facility would need the capacity to stockpile excavated material, treated material, and armor rock, as well as space for treatment. Institutional controls such as fencing and warning signs would also be needed at the off-site facility. Material stockpiles (both untreated and treated) would need to be managed to control runoff using covers for the stockpiles and silt fencing. Dust controls may also be needed. Requirements for shipping hazardous materials would be followed, including packaging in appropriate containers and proper labeling. The FS notes that water generated from sediment dewatering would need to be treated on-site for discharge, or collected and transported off-site for disposal, depending on water quality.

Summary

Several alternatives have been presented in the FS for remediation of the San Jacinto River Waste Pits Superfund Site. BMPs have been examined for the remediation activities planned for each of the alternatives. Alternative 1N (no further action) and Alternative 2N (implementation of MNR and ICs) will not disturb the existing TCRA Armor and would not generate resuspension, residuals or release that would require BMPs outside the planned monitoring and maintenance. Alternative 3N includes addition of armor stone to flatten slopes of the TCRA cap, as well as construction of a submerged perimeter berm to protect the Permanent Cap. As the TCRA cap will remain in place providing protection from the underlying sediments, generation of resuspension or releases is unlikely, and therefore does not require BMPs beyond the planned MNR and ICs. Alternative 4N requires partial removal of the TCRA cap, S/S of the underlying sediments, restoration of the armored cap and implementation of MNR and ICs. The slopes of the remaining cap would be flattened and a perimeter berm installed to protect the Permanent Cap. A number of BMPs are recommended to manage resuspension from Alternative 4 activities. Installation of sheet pile walls is planned. As noted previously, better seals between joints may be achieved if the existing armor cap is removed from the sheet pile footprint prior to installation. The sheet pile should be in place to capture resuspension during removal of the existing TCRA cap, S/S, and restoration of the armored cap. If dewatering is conducted, the effluent may need to be treated or shipped to a licensed facility. Controls such as silt fence are needed to manage runoff from upland areas of the site. Application of water may be needed to control dust. The removed cap material should be handled to avoid spreading contamination or recontaminating the site. Removed geotextile and geomembrane and contaminated armor stone should be disposed in appropriate containers for transport to landfill. As discussed in the FS, direct loading into trucks for transport to the disposal facility may eliminate the need for stockpiles. Periodic equipment cleaning and decontamination of trucks prior to leaving the site may reduce tracking contaminants off site. A plan to sequence cap removal, S/S and cap restoration activities is needed to minimize equipment tracking between clean and contaminated areas. This may include segmenting the site into subareas. Upon completion of S/S, monitoring should be conducted to determine residual contamination. Residual contamination is addressed to some extent by the planned Permanent Cap, MNR and ICs. Activated carbon may be dispersed in the water column or placed on the stabilized surface prior to capping as needed to further manage resuspension or releases in the water column or surface residuals. Flocculant may also be used to limit losses of resuspended solids during removal of the sheet pile. Alternative 5N requires partial removal of the TCRA cap, and excavation of the underlying sediments, followed by restoration of the armored cap, enhancement of the remaining cap, perimeter berm installation, MNR and ICs. Rather than sheet pile walls, silt curtain is suggested in the FS to manage resuspended material from Alternative 5N activities. As experienced in the TCRA cap construction (Anchor QEA 2012), silt curtains can be problematic and will need to be managed throughout the duration of the construction activities. Sheet pile walls would provide much better control of contaminant releases, residuals and resuspension for these highly contaminated materials. As with Alternative 4N, flocculants or activated carbon may be needed to treat resuspended solids or dissolved contaminants trapped by the sheet pile wall prior to its removal, but would not provide much benefit if a silt curtain were used for resuspension control. For upland activities, runoff controls (silt fence and/or hay bales) and dust control are needed. As used in the TCRA activities, a temporary water control berm may be installed to reduce inundation of the upland area by tidal water. A work plan is needed to determine optimal sequence for working in different areas of the site to minimize cross contamination, as well as decontamination of equipment prior to exiting the site. Staging the construction, may also reduce the surface area exposed at a given time, reducing the risk of contaminant releases during flood events. Residual contamination may be addressed by the use of a cleanup pass of either the dredge or land-based equipment. Prior to cap restoration, the area will be backfilled. If post-excavation monitoring indicates the need for additional residual management, activated carbon could be placed to provide sequestration of contaminants.

Alternative 5aN includes more extensive removal of the TCRA cap and excavation of underlying sediments which would be subsequently backfilled. Armor stone would be added to flatten the remaining existing cap slope, and the perimeter berm would be constructed along with MNR and ICs. Alternative 5aN includes the use of a perimeter berm in shallow areas which would transition to sheet pile walls in deeper water. The berm and sheet pile would serve to contain resuspended sediments during construction activities. As with Alternatives 4N and 5N, cross contamination should be minimized through work sequencing and decontamination of equipment. Removed cap material should be properly contained and shipped to a landfill, although clean armor rock may be reused. Other BMPs for upland areas include the use of silt fence to control runoff and water spraying for dust control. Water control berms could also be used to minimize tidal inundation of upland areas. Resuspended solids trapped behind the sheet pile/berm could be managed by allowing it to settle, or by addition of flocculant to promote settling. Similarly, dissolved contaminants could be treated by addition of activated carbon. Activated carbon may also be used to treat residual contamination left on the surface of the excavated area prior to backfill. A cleanup pass may also be useful to remove residual contamination from the surface. Backfill should be placed carefully to avoid disturbing the underlying soil/sediment. An off-site facility will likely be used to stockpile materials and treat excavated sediment prior to transportation to a landfill. The off-site location will also require dust and runoff controls as well as institutional controls. Water from dewatering would need to be treated on-site for discharge or collected and transported off-site for disposal. Alternative 6N involves complete removal of the TCRA cap and excavation of all soils and sediments exceeding 220 *ng/kg* $TEQ_{DF,M}$, including the area near the Upland Sand Separation Area. The areas would be subsequently backfilled, and ICs and MNR implanted. A permanent cap is not included in this alternative. To manage resuspension, a silt curtain is planned, although sheet pile was mentioned as a possibility. Sheet pile would likely be more effective for controlling resuspension. Resuspended solids trapped behind the silt curtain should be allowed to settle prior to curtain removal. Residual contamination may also be managed by addition of activated carbon to the surface either before backfilling or as a component of the backfill material. Silt fence is recommended to manage upland runoff, and water spraying for dust control at both the upland portion of the SJRWP site, as well as at the off-site staging area.

Task 13

Statement

Assess the validity of statements made in the Feasibility Study that the remedial alternative with removal, solidification, and placing wastes again beneath the TCRA cap has great uncertainty as to implementation and that such management of the waste will result in significant releases.

Findings

Task 20

Statement

Assess the appropriateness of the preliminary sediment remediation action level of 220 *ng/kg* in consideration of the appropriate exposure scenario (recreational vs. subsistence fishing), and in consideration of an appropriate Relative Bio-Availability (RBA) factor; and recommend an alternative sediment action level as appropriate.

Analysis of Sediment Protective Concentration Levels (PCL) for Dioxin/Furans

The FS uses human health Sediment Protective Concentration Levels (PCLs) for Dioxin/Furans based on consideration of reasonable potential future uses within the Site Perimeter. The potential future site use includes both exposure to sediment by a hypothetical recreational fisher and a hypothetical recreational visitor, and exposure to soils by a hypothetical construction worker and a hypothetical commercial worker. The development of PCLs for the various exposure scenarios considered all potential exposure pathways associated with each hypothetical receptor and each medium.

Child Recreational Visitor PCL

As described in the May 2013 Remedial Investigation Report, Integral used methods described by USEPA (1991) guidance to calculate PCLs to address all assumed pathways of direct exposure to a single environmental medium (such as sediment, soil, or tissue). The RI states that guidance does not require that combined exposures to more than one environmental medium be considered. As such, the RI has assumed that sediments and soils to which a child recreational visitor is exposed are separate media with fractional exposure (F_{SOIL} or F_{SED}) set to 0.5.

It should be expected that a child recreational visitor is using the shoreline and primarily exposed to sediments that exist both above and below the water line. As such the exposure model should identify sediment as the primary exposure medium with the sediment intake fraction (F_{SED}) set to 1.00. A separate PCL can also be developed for a child recreational visitor primarily exposed to upland soils with the soil intake fraction (F_{SOIL}) set to 1.00. As developed, the sediment and soil RME and CTE PCLs for a child recreational visitor are double the concentration for what should be considered protective concentration due to use of a fractional exposure.

In regards to the incidental ingestion Relative Bioavailability Adjustment for soil and sediment (RBA_{SS}), modifying the value from 0.5 to 1.0 has little impact on the PCL estimated for recreational visitors exposed to sediment, changing the PCL from 220 *ng/kg* $TEQ_{DF,M}$ to 200 *ng/kg* $TEQ_{DF,M}$, because the primary route of exposure for this scenario is dermal exposure. More significant changes are observed for commercial and construction workers due to the lower relative exposure through dermal uptake compared to ingestion of soil and sediment through gut uptake. The dermal absorption factor (ABSd) used for development of soil and sediment PCLs is 0.03 which has been recommended by the USEPA.

The currently available information suggests that an ingestion RBA for dioxin in soils can be expected to be less than 100%; however, available estimates of soil dioxin RBA are not adequate and sufficient to estimate a value for RBA for use in risk assessment as an alternative to 100% or site-specific values. Publications that address the effects of weathering of hydrocarbon mixtures, binding to black carbon and the resulting bioavailability of polycyclic aromatic hydrocarbons (PAHs) have no bearing on the bioavailability of dioxins and furans due to the differences in the binding chemistry of aromatic hydrocarbons vs chlorinated hydrocarbons to geosorbents.

A site specific RBA_{SS} has been developed for contaminated floodplain soils and sediments along the Tittabawassee River in Michigan. The RBA_{SS} developed for this site ranged from 0.43 to 0.51 depending on the carrier medium used for toxicological studies. The PRP provided evidence showing that a high proportion of the D/F TEQ measured in floodplain soils is strongly associated with particulate anthropogenic black carbon that was specific to the chloralkali production process that also generated the dioxins and furans. Unlike the San Jacinto data set, no correlation was observed between D/F TEQ distribution and finer sub-fractions of the soil and natural organic matter. Partitioning of dioxins and furans in the surface water of the San Jacinto River has been extensively evaluated and, as discussed in Section 5.2.6 of the Chemical Fate and Transport Modeling Study (Anchor QEA 2012b), has been found to generally conform to expected behavior, when dissolved organic carbon is taken into account.

Application of sediment intake fraction (F_{SED}) set to 1.00 and use of RBA_{SS} set to 1.0 would result in a sediment RME PLC of 100 *ng/kg* for the child recreational visitor. Development of a soil RME PLC for the child recreational visitor with the intake fraction (F_{SOIL}) set to 1.00 and use of RBA_{SS} set to 1.0 should be developed for the Feasibility Study.

Recreational Fisher

In the Remedial Investigation, sediment and tissue PCLs have been developed separately for the recreational fisher based on assumed potential fish and shellfish consumption by a young child. The sediment non-cancer RME PCL for recreational fisher assumes that the exposure is entirely from sediment (F_{SED}= 1.0) and a fraction of intake that is site-related ($FI_{SOIL\text{-}SED}$) equal to 1.0 resulting in a PCL $TEQ_{DF,M}$ for sediment of 299 *ng/kg* (note that this value should be adjusted using a RBA_{SS} of 1.0). For the Fish and Shellfish RME PCLs, the fraction of total intake that is site related (FI_{TISSUE}) is 0.25 and the RBA_{TISSUE} is 1.0. For the consumption of fish and shellfish, the risk model results in tissue RME PCLs of 3.8 and 89 *ng/kg* $TEQ_{DF,M}$ for fish and shellfish tissue, respectively.

A fundamental problem exists for the feasibility study. The PCLs designed for protection of child recreational fishers have not been translated into PCLs for sediment contaminants that can be incorporated into remedial action objectives. This is significant since consumption of fish and shellfish accounts for 95% or more of the dioxin and furan exposure to child recreational fishers. The direct exposure to sediments through dermal contact and incidental ingestion accounts for 5% or less of the dioxin and furan exposure. RAOs designed to address the majority of risk to child recreational fishers are needed.

The data analyses and literature review presented in the Technical Memorandum on Bioaccumulation Modeling (Integral 2010) claims that dioxin and furan congeners do not predictably bioaccumulate in fish or invertebrate tissue based on the available tissue data and sediment data. Appendix B for the RI provides correlations between fish fillet tissue wet weight concentrations and bulk sediment concentrations for individual congeners. The differences in individual congener chemistry, variability in sediment geochemistry, and variability in the size and biochemistry of individual organisms as well as variability in the ecological predator/prey relationships within the site food web ultimately result in the large variance for the relationship between sediment and biota tissue concentrations. Therefore, it is not surprising that correlations were weak between fish fillet tissue wet weight concentrations and bulk sediment dry weight concentrations for individual congeners.

The ratio provided in Appendix B is identified as a biota-sediment accumulation factor (BSAF); however, the analysis did not follow standard practice which would define BSAF as the lipid normalized tissue concentration relative to an organic carbon normalized sediment concentration. Prediction of fillet concentrations can then be made following statistical analysis of the BSAF correlation for whole fish tissue. Even with the absence of sediment organic carbon content and tissue lipid content for whole fish in Integral's correlation analysis, a significant association of fillet wet weight tissue concentrations with sediment dry weight concentrations was observed for both tetrachlorinated dioxins and furans. The 2,3,7,8 dioxin and furan congeners were observed to be the dominant congeners in fish tissue when expressed in both terms of absolute mass and TEQ potential.

A simplistic approach to developing fish and shellfish sediment PCL can be developed that is not based on mechanistic bioaccumulation models or the systematic analysis of congener uptake by fish and shellfish, but is instead based on the central tendency of D/F concentrations found in tissue and sediments. Using the central tendency for establishing a sediment PCL is less satisfying than more rigorous modeling approaches designed to associate sediment concentrations to tissue concentrations; however, it has merit when RAOs are also based on the central tendency of a surface area-weighted average $TEQ_{DF,M}$ ($TEQ_{DF,M}$ SWAC).

One simplistic approach is to take the net increase in the central tendency for tissue concentrations (*i.e.*, site value [mean or median] minus the background value) and simply relate this to the net increase in the central tendency for sediment concentrations. This ratio (a generic bioaccumulation factor for all site sediments) can then be applied as a PCL specific for evaluating remedial alternatives that are based on a SWAC.

For example:

- The mean net increase in Hardhead Catfish fillet $TEQ_{DF,M}$ for all site samples is (3.367 *ng/kg* - 0.865 *ng/kg*) = 2.502 *ng/kg* $TEQ_{DF,M}$ based on Tables 4-12 and 5-16 of the Remedial Investigation where the background fish fillet tissue concentration is 0.865 *ng/kg* $TEQ_{DF,M}$.

- The mean net increase in sediment $TEQ_{DF,M}$ for all site samples is (875 *ng/kg* -1.17 *ng/kg*) = 874 *ng/kg* $TEQ_{DF,M}$ based on Tables 4-5 and 5-7 where the background sediment concentration is 1.17 *ng/kg* $TEQ_{DF,M}$.

- The central tendency for the bioaccumulation factor for a net change in fish fillet tissue $TEQ_{DF,M}$ that is associated with the net increase in sediment $TEQ_{DF,M}$ (2.502 *ng/kg* $TEQ_{DF,M}$ / 874 *ng/kg* $TEQ_{DF,M}$) is 0.00286.

- For the Fish Fillet Tissue RME PCL of 3.8 *ng/kg* $TEQ_{DF,M}$ @ 25% site fish consumption and 0.95 *ng/kg* $TEQ_{DF,M}$ @ 100% site fish consumption, the net allowable change in fish fillet tissue $TEQ_{DF,M}$ above the background fillet tissue concentration of 0.865 ng/kg $TEQ_{DF,M}$ is 0.085 *ng/kg* $TEQ_{DF,M}$ @ 100% site fish consumption and 0.34 *ng/kg* $TEQ_{DF,M}$ @ 25% site fish consumption and 75% background fish consumption.

- The allowable net increase in sediment $TEQ_{DF,M}$ above background is 30 *ng/kg* $TE_{QDF,M}$ (0.085 *ng/kg* $TE_{QDF,M}$ / 0.00286) for 100% consumption from the site and 119 *ng/kg* $TE_{QDF,M}$ (0.34 *ng/kg* $TE_{QDF,M}$ / 0.00286) for 25% consumption from the site.

- Adding the background sediment concentration of 1.17 *ng/kg* to the allowable net increase in sediment $TEQ_{DF,M}$ and accounting for only 95% exposure from fish consumption yields a calculated sediment PCL value of 29 *ng/kg* sediment $TEQ_{DF,M}$ for 100% site fish consumption and 114 *ng/kg* sediment $TEQ_{DF,M}$ for 25% site fish consumption for the Child Recreational Fisher exposure scenario used in the Remedial Investigation.

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Appendix A

Description of LTFATE Modeling System

LTFATE is a multi-dimensional modeling system maintained by ERDC. The hydrodynamic module in LTFATE is the Environmental Fluid Dynamics Code (EFDC) surface water modeling system (Hamrick 2007a; 2007b; and 2007c). EFDC is a public domain, three-dimensional finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. Brief descriptions of these two modules are described below.

Hydrodynamic module in LTFATE

EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow. It solves the three-dimensional (3D), vertically hydrostatic, free surface, turbulence averaged equations of motion. EFDC is extremely versatile, and can be used for 1D, 2D-laterally averaged (*2DV*), 2D-vertically averaged (2DH), or 3D simulations of rivers, lakes, reservoirs, estuaries, coastal seas, and wetlands.

For realistic representation of horizontal boundaries, the governing equations in EFDC are formulated such that the horizontal coordinates, x and y, are curvilinear. To provide uniform resolution in the vertical direction, the sigma (stretching) transformation is used. The equations of motion and transport solved in EFDC are turbulence-averaged, because prior to averaging, although they represent a closed set of instantaneous velocities and concentrations, they cannot be solved for turbulent flows. A statistical approach is applied, where the instantaneous values are decomposed into mean and fluctuating values to enable the solution. Additional terms that represent turbulence are introduced to the equations for the mean flow. Turbulent equations of motion are formulated to utilize the Boussinesq approximation for variable density. The Boussinesq approximation accounts for variations in density only in the gravity term. This assumption simplifies the governing equations significantly, but may introduce large errors when density gradients are large.

The resulting governing equations, presented in Appendix B, include parameterized, Reynolds-averaged stress and flux terms that account for the turbulent diffusion of momentum, heat and salt. The turbulence parameterization in EFDC is based on the Mellor and Yamada (1982) level 2.5 turbulence closure scheme, as modified by Galperin *et al.* (1988), that relates turbulent correlation terms to the mean state variables. The EFDC model also solves several transport and transformation equations for different dissolved and suspended constituents, including suspended sediments, toxic contaminants, and water quality state variables. Detailed descriptions of the model formulation and numerical solution technique used in EFDC are provided by Hamrick (2007b). Additional capabilities of EFDC include: 1) simulation of wetting and drying of flood plains, mud flats, and tidal marshes; 2) integrated, near-field mixing zone model; 3) simulation of hydraulic control structures such as dams and culverts; and 4) simulation of wave boundary layers and wave-induced mean currents. A more detailed description of EFDC is given in Appendix B.

Sediment transport module

The sediment transport model in LTFATE is a modified version of the SEDZLJ mixed sediment transport model (Jones and Lick 2001; James *et al.* 2010) that a) includes a three-dimensional representation of the sediment bed, and b) can simulate winnowing and armoring of the surficial layer of the sediment bed. SEDZLJ is dynamically linked to LTFATE in that the hydrodynamics and sediment transport modules are both run during each model time step. This enables simulated changes in morphology to be instantly fed-back to the hydrodynamic model. A more detailed description of SEDZLJ is given in Appendix C.

One of the first steps in performing sediment transport modeling is to use grain size distribution data from sediment samples collected at different locations throughout the model domain to determine how many discrete sediment size classes are needed to adequately represent the full range of sediment sizes. Typically, three to eight size classes are used. For example, AQ used four sediment size classes in their sediment transport model of the SJR. One size class was used to represent sediment in the cohesive sediment size range, 5 μm, and three size classes were used to represent the noncohesive sediment size range, 140, 510 and 3,500 μm.

Appendix B

Description of LTFATE Hydrodynamic Module

EFDC is a public domain, 3D finite difference model that contains dynamically linked hydrodynamic and sediment transport modules. EFDC can simulate barotropic and baroclinic flow in a water body due to astronomical tides, wind, density gradients, and river inflow. It solves the 3D vertically hydrostatic, free surface, turbulence averaged equations of motion. EFDC can be used for 1D, 2D-laterally averaged (*2DV*), 2D-vertically averaged (2DH), or 3D simulations of rivers, lakes, reservoirs, estuaries, coastal seas, and wetlands.

EFDC solves the 3D Reynolds-averaged equations of continuity (Equation B-1), linear momentum (Equations B-2 and B-3), hydrostatic pressure (Equation B-4), equation of state (Equation B-5) and transport equations for salinity and temperature (Equations B-6 and B-7) written for curvilinear-orthogonal horizontal coordinates and a sigma (stretching) vertical coordinate. These are given by Hamrick (2007b) and repeated below:

$$\frac{\partial(m\varepsilon)}{\partial t} + \frac{\partial(m_y Hu)}{\partial x} + \frac{\partial(m_x Hv)}{\partial y} + \frac{\partial(mw)}{\partial z} = 0 \qquad \text{(B-1)}$$

$$\frac{\partial(mHu)}{\partial t} + \frac{\partial(m_y Huu)}{\partial x} + \frac{\partial(m_x Hvu)}{\partial y} + \frac{\partial(mwu)}{\partial z} -$$

$$(mf + v\frac{\partial(m_y)}{\partial x} - u\frac{\partial m_x}{\partial y})Hv = m_y H\frac{\partial(g\varepsilon + p)}{\partial x} - \qquad \text{(B-2)}$$

$$m_y(\frac{\partial H}{\partial x} - z\frac{\partial H}{\partial x})\frac{\partial p}{\partial z} + \frac{\partial(mH^{-1}A_v\frac{\partial u}{\partial z})}{\partial z} + Q_u$$

$$\frac{\partial(mHv)}{\partial t} + \frac{\partial(m_y Huv)}{\partial x} + \frac{\partial(m_x Hvv)}{\partial y} + \frac{\partial(mwv)}{\partial z} +$$

$$(mf + v\frac{\partial(m_y)}{\partial x} + u\frac{\partial m_x}{\partial y})Hu = m_x H\frac{\partial(g\varepsilon + p)}{\partial y} - \tag{B-3}$$

$$m_x(\frac{\partial H}{\partial y} - z\frac{\partial H}{\partial y})\frac{\partial p}{\partial z} + \frac{\partial(mH^{-1}A_v\frac{\partial v}{\partial z})}{\partial z} + Q_v$$

$$\frac{\partial p}{\partial z} = \frac{gH(\rho - \rho_o)}{\rho_o} = gHb \tag{B-4}$$

$$\rho = \rho\left(\rho, S, T\right) \tag{B-5}$$

$$\frac{\partial(mHS)}{\partial t} + \frac{\partial(m_y HuS)}{\partial x} + \frac{\partial(m_x HvS)}{\partial y} + \frac{\partial(mwS)}{\partial z} = \frac{\partial(\frac{mA_b}{H}\frac{\partial S}{\partial z})}{\partial z} + Q_s \tag{B-6}$$

$$\frac{\partial(mHT)}{\partial t} + \frac{\partial(m_y HuT)}{\partial x} + \frac{\partial(m_x HvT)}{\partial y} + \frac{\partial(mwT)}{\partial z} = \frac{\partial(\frac{mA_b}{H}\frac{\partial T}{\partial z})}{\partial z} + Q_T \tag{B-7}$$

where u and v are the mean horizontal velocity components in (x,y) coordinates; m_x and m_y are the square roots of the diagonal components of the metric tensor, and $m = m_x m_y$ is the Jacobian or square root of the metric tensor determinant; p is the pressure in excess of the reference pressure, $\frac{\rho_o gH(1 - z)}{\rho_o}$, where ρ_o is the reference density; f is the Coriolis parameter for latitudinal variation; A_v is the vertical turbulent viscosity; and A_b is the vertical turbulent diffusivity. The buoyancy b in Equation B-4 is the normalized deviation of density from the reference value. Equation B-5 is the equation of state that calculates water density, ρ, as functions of p, salinity, S, and temperature, T.

The sigma (stretching) transformation and mapping of the vertical coordinate is given as:

$$z = \frac{(z^* + h)}{(\xi + h)} \tag{B-8}$$

where z^* is the physical vertical coordinate, and h and ξ are the depth below and the displacement about the undisturbed physical vertical coordinate origin, $z^* = 0$, respectively, and $H=h+\xi$ is the total depth. The vertical velocity in z coordinates, w, is related to the physical vertical velocity w^* by:

$$w = w^* - z\left(\frac{\partial \xi}{\partial t} + \frac{u}{m_x}\frac{\partial \xi}{\partial x} + \frac{v}{m_y}\frac{\partial \xi}{\partial y}\right) + (1 - z)\left(\frac{u}{m_x}\frac{\partial h}{\partial x} + \frac{v}{m_y}\frac{\partial h}{\partial y}\right) \qquad \text{(B-9)}$$

The solutions of Equations B-2, B-3, B-6 and B-7 require the values for the vertical turbulent viscosity and diffusivity and the source and sink terms. The vertical eddy viscosity and diffusivity, A_v and A_b, are parameterized according to the level 2.5 (second-order) turbulence closure model of Mellor and Yamada (1982), as modified by Galperin *et al.* (1988), in which the vertical eddy viscosities are calculated based on the turbulent kinetic energy and the turbulent macroscale equations. The Mellor and Yamada level 2.5 (MY2.5) turbulence closure model is derived by starting from the Reynolds stress and turbulent heat flux equations under the assumption of a nearly isotropic environment, where the Reynolds stress is generated due to the exchange of momentum in the turbulent mixing process. To make the turbulence equations closed, all empirical constants are obtained by assuming that turbulent heat production is primarily balanced by turbulent dissipation.

The vertical turbulent viscosity and diffusivity are related to the turbulent intensity, q^2, turbulent length scale, l and a Richardson number R_q as follows:

$$A_v = \Phi_v q l = 0.4(1 + 36R_q)^{-1}(1 + 6R_q)^{-1}(1 + 8R_q) q l \qquad \text{(B-10)}$$

$$A_b = \Phi_b q l = 0.5(1 + 36R_q)^{-1} q l \qquad \text{(B-11)}$$

where A_v and A_b are stability functions that account for reduced and enhanced vertical mixing or transport in stable and unstable vertical, density-stratified environments, respectively, and the local Richardson number is given as:

$$R_q = \frac{gH\frac{\partial b}{\partial z}}{q^2}\frac{l^2}{H^2} \qquad \text{(B-12)}$$

A critical Richardson number, R_q = 0.20, was found at which turbulence and mixing cease to exist (Mellor and Yamada 1982). Galperin *et al.* (1988) introduced a length scale limitation in the MY scheme by imposing an upper limit for the mixing length to account for the limitation of the vertical turbulent excursions in stably stratified flows. They also modified and introduced stability functions that account for reduced or enhanced vertical mixing for different stratification regimes.

The turbulence intensity (q^2) and the turbulence length scale (l) are computed using the following two transport equations:

$$\frac{\partial(mHq^2)}{\partial t} + \frac{\partial(m_y Huq^2)}{\partial x} + \frac{\partial(m_x Hvq^2)}{\partial y} + \frac{\partial(mwq^2)}{\partial z} = \frac{\partial\left(\frac{mA_q\frac{\partial q^2}{\partial z}}{H}\right)}{\partial z} + Q_q \qquad \text{(B-13)}$$
$$+ 2\frac{mA_v}{H}\left(\left(\frac{\partial^2 u}{\partial z^2}\right) + \left(\frac{\partial^2 v}{\partial z^2}\right)\right) + 2mgA_b\frac{\partial b}{\partial z} - 2mH\left(\frac{q^3}{(B_1 l)}\right)$$

$$\frac{\partial(mHq^2 l)}{\partial t} + \frac{\partial(m_y Huq^2 l)}{\partial x} + \frac{\partial(m_x Hvq^2 l)}{\partial y} + \frac{\partial(mwq^2 l)}{\partial z} =$$
$$\frac{\partial\left(\frac{mA_q\frac{\partial q^2 l}{\partial z}}{H}\right)}{\partial z} + Q_l + 2\frac{mE_1 lA_v}{H}\left(\left(\frac{\partial^2 u}{\partial z^2}\right) + \left(\frac{\partial^2 v}{\partial z^2}\right)\right) + mgE_1E_3 lA_b\frac{\partial b}{\partial z} \qquad \text{(B-14)}$$
$$- H\left(\frac{q^3}{(B_1)}\right)(1 + E_2(\kappa L)^{-2}l^2)$$

The above two equations include a wall proximity function, $W = 1 + E_2 l(\kappa L)^{-2}$, that assures a positive value of diffusion coefficient $L^{-1} = (H)^{-1}(z^{-1} + (1 - z)^{-1})$. κ, B_1, E_1, E_2, and E_3 are empirical constants with values 0.4, 16.6, 1.8, 1.33, and 0.25, respectively. All terms with *Q's* (Q_u, Q_v, Q_q, Q_l, Q_s, Q_T) are sub-grid scale sink-source terms that are modeled as sub-grid scale horizontal diffusion. The vertical diffusivity, A_q, is in general taken to be equal to the vertical turbulent viscosity, A_v (Hamrick 2007b).

The vertical boundary conditions for the solutions of the momentum equations are based on the specification of the kinematic shear stresses. At the bottom, the bed shear stresses are computed using the near bed velocity components (u_1,v_1) as:

$$(\tau_{bx},\tau_{by}) = c_b\sqrt{u_1^2 + v_1^2}(u_1,v_1) \qquad \text{(B-15)}$$

where the bottom drag coefficient $c_b = (\frac{\kappa}{\ln(\Delta_1/2z_o)})^2$, where κ is the von Karman constant, Δ_1 is the dimensionless thickness of the bottom layer, $z_o = z_o^*/H$ is the dimensionless roughness height, and z_o^* is roughness height in meters. At the surface layer, the shear stresses are computed using the *u, v* components of the wind velocity (u_w,v_w) above the water surface (usually measured at 10 m above the surface) and are given as:

$$(\tau_{sx},\tau_{sy}) = c_s\sqrt{u_w^2 + v_w^2}(u_w,v_w) \qquad \text{(B-16)}$$

where $c_s = 0.001\frac{\rho_a}{\rho_w}(0.8 + 0.065\sqrt{u_w{}^2 + v_w^2})$ and ρ_a and ρ_w are the air and water densities, respectively. Zero flux vertical boundary conditions are used for the transport equations.

Numerically, EFDC is second-order accurate both in space and time. A staggered grid or C-grid provides the framework for the second-order accurate spatial finite differencing used to solve the equations of motion. Integration over time involves an internal-external mode splitting procedure separating the internal shear, or baroclinic mode, from the external free surface gravity wave, or barotropic mode. In the external mode, the model uses a semi-implicit scheme that allows the use of relatively large time steps. The internal equations are solved at the same time step as the external equations, and are implicit with respect to vertical diffusion. Details of the finite difference numerical schemes used in the EFDC model are given in Hamrick (2007b), and will not be presented in this report.

The generic transport equation solved in EFDC for a dissolved (*e.g.*, chemical contaminant) or suspended (*e.g.*, sediment) constituent having a mass per unit volume concentration *C*, is

$$\frac{\partial m_x m_y HC}{\partial t} + \frac{\partial m_y HuC}{\partial x} + \frac{\partial m_x HvC}{\partial y} + \frac{\partial m_x m_y wC}{\partial z} - \frac{\partial m_x m_y w_{sc} C}{\partial z} = \frac{\partial}{\partial x}\left(\frac{m_y}{m_x} HK_H \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{m_x}{m_y} HK_H \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(m_x m_y \frac{K_v}{H}\frac{\partial C}{\partial z}\right) + Q_c \qquad \text{(B-17)}$$

where K_V and K_H are the vertical and horizontal turbulent diffusion coefficients, respectively; w_{sc} is a positive settling velocity when C represents the mass concentration of suspended sediment; and Q_c represents external sources or sinks and reactive internal sources or sinks. For sediment, $C = S_i$, where S_i represents the concentration of the *ith* sediment class. So, Eq. B-17, which is the 3D advective-dispersive transport equation, is solved for each of the sediment size classes that the grain size distribution at the site is divided into. In this case, Q_{ci} = source/sink term for the *ith* sediment size class that accounts for erosion/deposition. The equation used to calculate Q_{ci} is the following:

$$S_i = E_{sus,i} - D_{sus,i} \qquad \text{(B-18)}$$

where $E_{sus,i}$ = sediment erosion rate for the *ith* sediment size class that is eroded and entrained into suspension, and $D_{sus,i}$ = sediment deposition rate for the *ith* sediment size class. Expressions for $D_{sus,i}$ and $E_{sus,i}$ are given later in this chapter.

The solution procedure for Eq. B-17 is the same as that for the salinity and heat transport equations, which use a high-order upwind difference solution scheme for the advection terms (Hamrick 2007b). Although the advection scheme is designed to minimize numerical diffusion, a small amount of horizontal diffusion remains inherent in the numerical scheme. As such, the horizontal diffusion terms in Equation B-17 are omitted by setting K_H equal to zero.

Appendix B

Description of LTFATE Sediment Transport Module

The sediment transport model in LTFATE is a modified version of the SEDZLJ mixed sediment transport model (Jones and Lick 2001; James *et al.* 2010) that includes a 3D representation of the sediment bed, and can simulate winnowing and armoring of the surficial layer of the sediment bed. SEDZLJ is dynamically linked to LTFATE in that the hydrodynamic and sediment transport modules are both run during each model time step.

Suspended Load Transport of Sediment

LTFATE solves Equation B-17 for the transport of each of the sediment classes to determine the suspension concentration for each size class in every water column layer in each grid cell. Included in this equation is the settling velocity, w_{sc}, for each sediment size class. The settling velocities for noncohesive sediments are calculated in SEDZLJ using the following equation (Cheng 1997):

$$W_s = \frac{\mu}{d}\left(\sqrt{25+1.2d_*^2}-5\right)^{\frac{3}{2}} \tag{C-1}$$

where μ = dynamic viscosity of water; d = sediment diameter; and d_* = non-dimensional particle diameter given by:

$$d_* = d\left[\left(\rho_s/\rho_w - 1\right)g/\nu^2\right]^{1/3} \tag{C-2}$$

where ρ_w = water density, ρ_s = sediment particle density, g = acceleration due to gravity, and ν = kinematic fluid viscosity. Cheng's formula is based on measured settling speeds of real sediments. As a result it produces slower settling speeds than those given by Stokes' Law because real sediments have irregular shapes and thus a greater hydrodynamic resistance than perfect spheres as assumed in Stokes' law.

For the cohesive sediment size classes, the settling velocities are set equal to the mean settling velocities of flocs and eroded bed aggregates determined from an empirical formulation that is a function of the concentration of suspended sediment.

The erosion and deposition of each of the sediment size classes, *i.e.*, the source/sink term in the 3D transport equation (Equation C-17), and the subsequent change in the composition and thickness of the sediment bed in each grid cell are calculated by SEDZLJ at each time step.

Description of SEDZLJ

The sediment bed model in LTFATE is the SEDZLJ sediment transport model (Jones and Lick 2001). SEDZLJ is dynamically linked to EFDC in LTFATE. SEDZLJ is an advanced sediment bed model that represents the dynamic processes of erosion, bedload transport, bed sorting, armoring, consolidation of fine-grain sediment dominated sediment beds, settling of flocculated cohesive sediment, settling of individual noncohesive sediment particles, and deposition. An active layer formulation is used to describe sediment bed interactions during simultaneous erosion and deposition. The active layer facilitates coarsening during the bed armoring process.

Figure C-1 shows the simulated sediment transport processes in SEDZLJ. In this figure, U = near bed flow velocity, δ_{bl} = thickness of layer in which bedload occurs, U_{bl} = average bedload transport velocity, D_{bl} = sediment deposition rate for the sediment being transported as bedload E_{bl} = sediment erosion rate for the sediment being transported as bedload, E_{sus} = sediment erosion rate for the sediment that is eroded and entrained into suspension, and D_{sus} = sediment deposition rate for suspended sediment. Specific capabilities of SEDZLJ are listed below.

- Whereas a hydrodynamic model is calibrated to account for the total bed shear stress, which is the sum of the form drag due to bed forms and other large-scale physical features and the skin friction (also called the surface friction), the correct component of the bed shear stress to

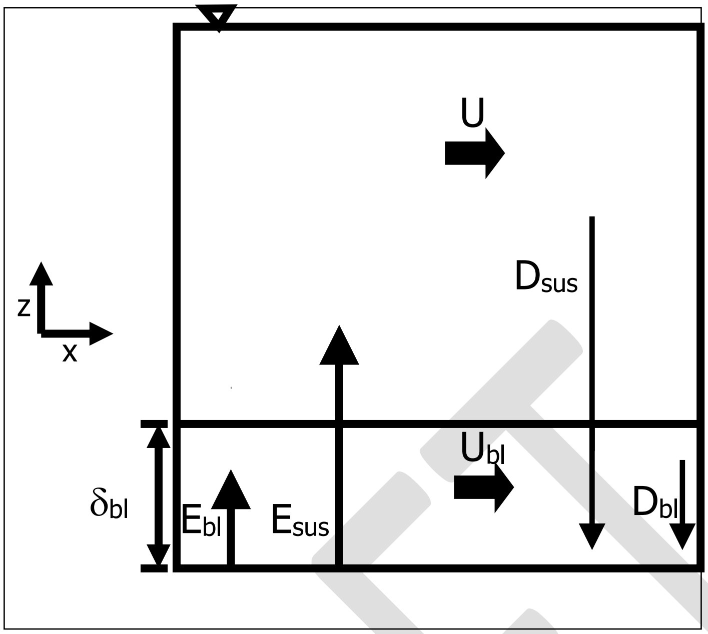

Figure C-1. Sediment transport processes simulated in SEDZLJ.

use in predicting sediment resuspension and deposition is the skin friction. The skin friction is calculated in SEDZLJ as a function of the near-bed current velocity and the effective bed roughness. The latter is specified in SEDZLJ as a linear function of the mean particle diameter in the active layer.

Multiple size classes of both fine-grain (*i.e.*, cohesive) and noncohesive sediments can be represented in the sediment bed. As stated previously, this capability is necessary to simulate coarsening and subsequent armoring of the surficial sediment bed surface during high flow events.

- To correctly represent the processes of erosion and deposition, the sediment bed in SEDZLJ can be divided into multiple layers, some of which are used to represent the existing sediment bed and others that are used to represent new bed layers that form due to deposition during model simulations. Figure C-2 shows a schematic diagram of this multiple bed layer structure. The graph on the right hand side of this figure shows the variation in the measured gross erosion rate (in units of *cm/s*) with depth into the sediment bed as a function of the applied skin friction. A SEDFLUME study is normally used to measure these erosion rates.

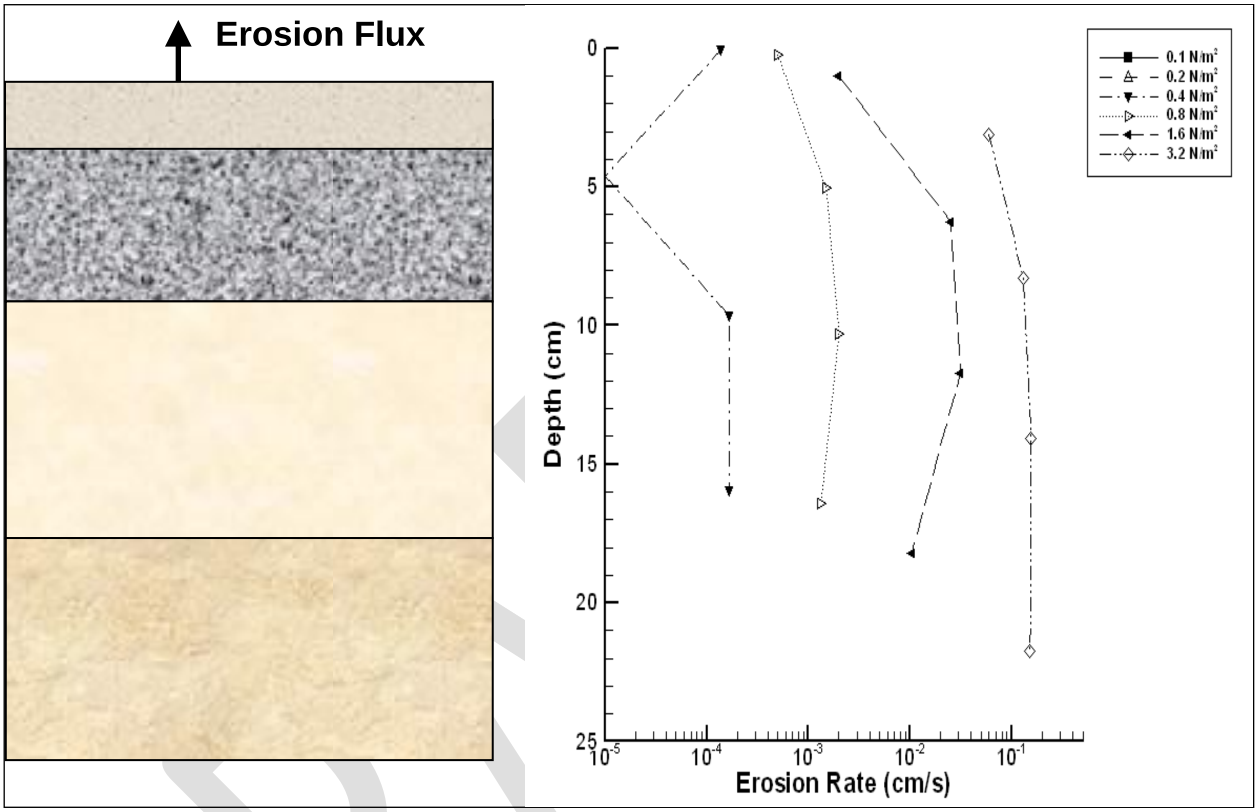

Figure C-2. Multi-bed layer model used in SEDZLJ.

- Erosion from both cohesive and non-cohesive beds is affected by bed armoring, which is a process that limits the amount of bed erosion that occurs during a high-flow event. Bed armoring occurs in a bed that contains a range of particle sizes (*e.g.*, clay, silt, sand). During a high-flow event when erosion is occurring, finer particles (*i.e.*, clay and silt, and fine sand) tend to be eroded at a faster rate than coarser particles (*i.e.*, medium to coarse sand). The differences in erosion rates of the various sediment particle sizes creates a thin layer at the surface of the sediment bed, referred to as the active layer, that is depleted of finer particles and enriched with coarser particles. This depletion-enrichment process can lead to bed armoring, where the active layer is primarily composed of coarse particles that have limited mobility. The multiple bed model in SEDZLJ accounts for the exchange of sediment through and the change in composition of this active layer. The thickness of the active layer is normally calculated as a time varying function of the mean sediment particle diameter in the active layer, the critical shear stress for resuspension corresponding to the mean particle diameter, and the bed shear stress. Figure C-3 shows a schematic of the active layer at the top of the multi-bed layer model used in SEDZLJ.

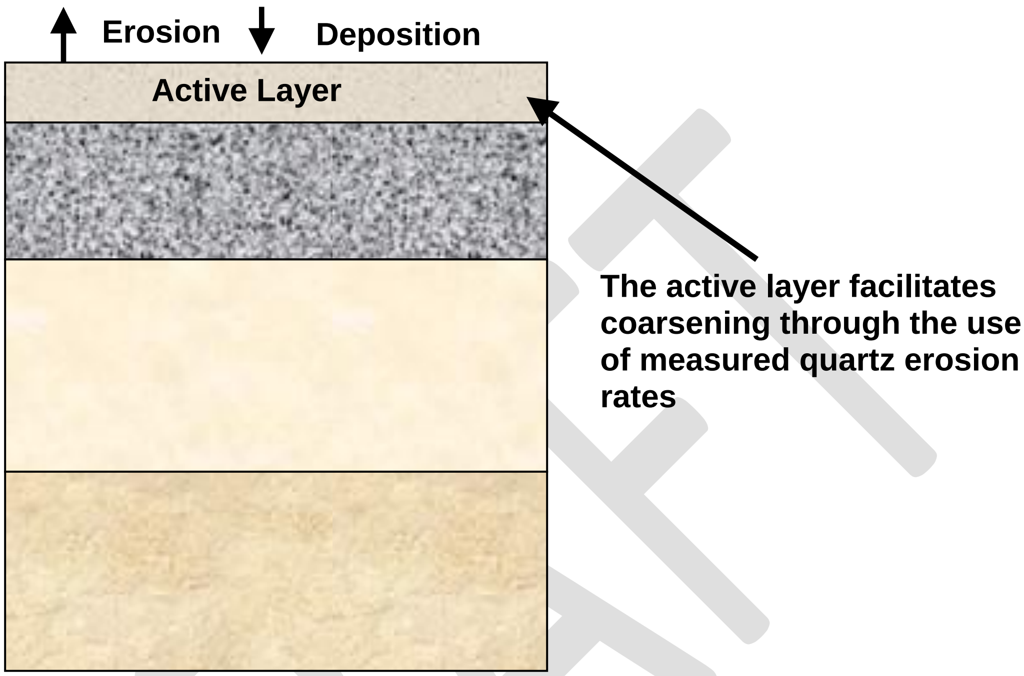

Figure C-3. Schematic of Active Layer used in SEDZLJ.

- SEDZLJ was designed to use the results obtained with SEDFLUME, which is a straight, closed conduit rectangular cross-section flume in which detailed measurements of critical shear stress of erosion and erosion rate as a function of sediment depth are made using sediment cores dominated by cohesive sediment collected at the site to be modeled (McNeil *et al*. 1996). However, when SEDFLUME results are not available, it is possible to use a combination of values for these parameters available from literature and/or the results of SEDFLUME tests performed at other similar sites. In this case, a detailed sensitivity analysis should be performed to assist in quantifying the uncertainty that results from the use of these non-site specific erosion parameters.

- SEDZLJ can simulate overburden-induced consolidation of cohesive sediments. An algorithm that simulates the process of primary consolidation, which is caused by the expulsion of pore water from the sediment, of a fine-grained, *i.e.*, cohesive, dominated sediment bed is included in SEDZLJ. The consolidation algorithm in SEDZLJ accounts for the following changes in two important bed parameters: 1) increase in bed bulk density with time due to the expulsion of pore water, and 2) increase in the bed shear strength (also referred to as the critical shear stress for resuspension) with time. The latter parameter is the minimum value of the bed shear stress at which measurable resuspension of cohesive sediment occurs. As such, the process of consolidation typically results in reduced erosion for a given excess bed shear stress (defined as the difference between the bed shear stress and the critical shear stress for erosion) due to the increase in the bed shear strength. In addition, the increase in bulk density needs to be represented to accurately account for the mass of sediment (per unit bed area) that resuspends when the bed surface is subjected to a flow-induced excess bed shear stress.

Models that represent primary consolidation range from empirical equations that approximate the increases in bed bulk density and critical shear stress for resuspension due to porewater expulsion (Sanford 2008) to finite difference models that solve the non-linear finite strain consolidation equation that governs primary consolidation in saturated porous media (*e.g.*, Arega and Hayter 2008). An empirical-based consolidation algorithm is included in SEDZLJ.

- SEDZLJ contains a morphologic algorithm that, when enabled by the model user, will adjust the bed elevation to account for erosion and deposition of sediment.

Bedload Transport of Noncohesive Sediment

The approach used by Van Rijn (1984) to simulate bedload transport is used in SEDZLJ. The 2D mass balance equation for the concentration of sediment moving as bedload is given by:

$$\frac{\partial\left(\delta_{bl}C_b\right)}{\partial t}=\frac{\partial q_{b,x}}{\partial x}+\frac{\partial q_{b,y}}{\partial y}+Q_b \tag{C-3}$$

where δ_{bl} = bedload thickness; C_b = bedload concentration; $q_{b,x}$ and $q_{b,y}$ = x- and y-components of the bedload sediment flux, respectively; and Q_b =

sediment flux from the bed. Van Rijn (1984) gives the following equation for the thickness of the layer in which bedload is occurring:

$$\delta_{bl} = 0.3dd_*^{0.7}(\Delta\tau)^{0.5} \tag{C-4}$$

where $\Delta\tau = \tau_b - \tau_{ce}$; τ_b = bed shear stress, and τ_{ce} = critical shear stress for erosion.

The bedload fluxes in the *x*- and *y*-directions are given by:

$$q_{b,x} = \delta_{bl}\, u_{b,x} C_b$$

$$q_{b,y} = \delta_{bl}\, u_{b,y} C_b$$

where $u_{b,x}$ and $u_{b,y}$ = *x*- and *y*-components of the bedload velocity, u_b, which van Rijn (1984) gave as

$$u_b = 1.5\tau_*^{0.6}\left[\left(\frac{\rho_s}{\rho_w} - 1\right)gd\right]^{0.5} \tag{C-5}$$

with the dimensionless parameter τ_* given as

$$\tau_* = \frac{\tau_b - \tau_{ce}}{\tau_{ce}} \tag{C-6}$$

The *x*- and *y*-components of u_b are calculated as the vector projections of the LTFATE Cartesian velocity components *u* and *v*.

The sediment flux from the bed due to bedload, Q_{bl}, is equal to

$$Q_b = E_{bl} - D_{bl} \tag{C-7}$$

Deposition of Sediment

In contrast to previous conceptual models, deposition of suspended noncohesive sediment and cohesive flocs is now believed to occur continually, and not just when the bed shear stress is less than a so-called critical shear stress of deposition (Mehta 2014). The rate of deposition of the *ith* sediment size class, $D_{sus,i}$ is given by:

$$D_{sus,i} = -\frac{W_{s,i}C_i}{d} \tag{C-8}$$

where $W_{s,i}$ is given by Eq. C-1 for noncohesive sediment and by the empirical formulation used for the settling velocities of suspended flocs and bed aggregates, and d = thickness of the bottom water column layer in a three-dimensional model. Because of their high settling velocities, noncohesive sediments deposit relatively quickly (in comparison to the deposition of cohesive sediments) under all flows. Due to the settling velocities of flocs being a lot slower than those of noncohesive sediment, the deposition rate of flocs are usually several orders of magnitude smaller.

Deposited cohesive sediments usually form a thin surface layer that is often called a fluff or benthic nepheloid layer that is often less than 1 cm in thickness. The fluff layer typically forms in estuaries and coastal waters via deposition of suspended flocs during the decelerating phase of tidal flows, in particular immediately before slack water (Krone 1972; and Hayter and Mehta 1986). The fluff layer is usually easily resuspended by the accelerating currents following slack water in tidal bodies of water.

The rate of deposition of the *ith* noncohesive sediment class moving as bedload is given by (James *et al*. 2010):

$$D_{bl,i} = -P_{bl,i} W_{s,i} C_{bl,i} \tag{C-9}$$

where $C_{bl,i}$ = mass concentration of the *ith* noncohesive sediment class being transported as bedload, and $P_{bl,i}$ = probability of deposition from bedload transport. The latter parameter is given by:

$$P_{bl,i} = \frac{E_{bl,i}}{W_{s,i} C_{bl,i}^{eq}} \tag{C-10}$$

where

$$C_{bl,i}^{eq} = \frac{0.18 C_o \tau_b}{d_*} \tag{C-11}$$

which is the steady-state sediment concentration in bedload that results from a dynamic equilibrium between erosion and deposition, d_* is given by Eq. C-2, and C_o = 0.65.

Erosion of Sediment

Erosion of a cohesive sediment bed occurs whenever the current and wave-induced bed shear stress is great enough to break the electrochemical interparticle bonds (Partheniades 1965; Paaswell 1973). When this happens, erosion takes place by the removal of individual sediment particles or bed aggregates. This type of erosion is time dependent and is defined as surface erosion or resuspension. In contrast, another type of erosion occurs more or less instantaneously by the removal of relatively large pieces of the bed. This process is referred to as mass erosion, and occurs when the bed shear stress exceeds the bed bulk strength along some deep-seated plane that is typically much greater than the bed shear strength of the surficial sediment.

The erosion rate of cohesive sediments, E, is given experimentally by:

$$\begin{aligned} E &= 0; && (\tau < \tau_{cr}) \\ E &= A\tau^{n}; && (\tau_{cr} < \tau < \tau_{m}) \\ E &= A\tau_{m}^{n}; && (\tau > \tau_{m}) \end{aligned} \tag{C-12}$$

where the exponent, coefficient, critical shear stress for erosion, and maximum shear stress (above which E is not a function of τ) n, A, and τ_{cr}, respectively, are determined from a SEDFLUME study. The erosion rates of the noncohesive sediment size classes were determined as a function of the difference between the bed shear stress and the critical shear stress for erosion using the results obtained by Roberts *et al.* (1998) who measured the erosion rates of quartz particles in a SEDFLUME.

The erosion rate of the *ith* noncohesive sediment size class that is transported as bedload, $E_{bl,i}$, is calculated by the following equation in which it is assumed there is dynamic equilibrium between erosion and deposition:

$$E_{bl,i} = P_{bl,i} W_{s,i} C_{bl,i} \tag{C-13}$$